Damages Calculation for Aquatic Resources: Coeur d'Alene Basin Natural Resource Damage Assessment

Prepared for:

United States Department of the Interior, Fish and Wildlife Service
United States Department of Agriculture, Forest Service
Coeur d'Alene Tribe

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August 20, 2004
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I. Introduction to Report and Authors

I.1 Introduction

This expert report contains the results of natural resource damage calculations for aquatic resources, which include surface water and the aquatic biota habitat services provided by surface water.

I.2 Information Considered

In developing the opinions presented in this report, the authors have relied on information developed by numerous investigators, including federal, tribal, and state resource agencies, contractors to federal, tribal, and state agencies, and academic researchers. The information developed by these various investigators (for example, fish population data, water quality data) is of the type that can be reasonable relied on for the analyses in this report. The analyses in this report have been conducted using accepted scientific and engineering methodology.

A full list of the data considered is presented in Chapter 5, Literature Cited, of this report.

I.3 Authors

This report contains the opinions and conclusions of Dr. Joshua Lipton, Dr. Frank Rahel, Mr. David Chapman, and Mr. Greg Koonce.

Dr. Lipton is an environmental toxicologist and Chief Executive Officer of Stratus Consulting Inc. in Boulder, Colorado. His resume is provided in the appendix. In the past four years, Dr. Lipton has provided testimony in the following matters:

- United States v. ASARCO Inc. et al., No. CV 96-0122-N-EJL
- United States v. The New Portland Meadows, Inc., et al. No. CV-3-00-00507-KI.

Dr. Lipton is responsible for report sections addressing damage calculation methodologies, surface water injury and service loss quantification, and replacement cost analyses as contained in report Chapters 1.0 (all subsections), 2.0 (all subsections), 4.0, 4.1, and 4.3.

Dr. Rahel is a fisheries biologist and a professor in the Department of Zoology and Physiology, University of Wyoming. His resume is provided in the appendix. In the past four years, Dr. Rahel has provided testimony in the following matter:

- United States v. ASARCO Inc. et al., No. CV 96-0122-N-EJL.

Dr. Rahel is responsible for report sections related to fish population and community ecology, quantification of fish services, surface water habitat enhancement, and service gains associated with habitat restoration, as presented in Sections 4.1, 4.2, 4.2.1, 4.2.2, 4.2.3, and 4.2.4.

Mr. David Chapman is an environmental and resource economist and a managing economist at Stratus Consulting Inc. in Boulder, Colorado. His resume is provided in the appendix.

Mr. Chapman is responsible for report sections related to the cost of acquisition of water, habitat equivalency analysis, and damage determinations. These sections include Chapter 3 and Section 4.3.

Mr. Greg Koonce is a fisheries biologist and principal at Inter-fluve, Inc. in Portland, Oregon. His resume is provided in the appendix. In the past four years, Mr. Koonce has provided testimony in the following matter:

- Peace River/Manasota Regional Water Supply Authority v. IMC Phosphates Company and the Florida Department of Environmental Protection. Nos. 03-0791, 03-0792, 03-0804, 03-0805, 03-1610, 03-3287, 03-3288, 03-3289.

Mr. Koonce is responsible for sections on ecological enhancement project feasibility and costs as contained in Sections 4.2.5 and 4.2.6.

I.4 Compensation Received

Dr. Lipton and Mr. Chapman are employees of Stratus Consulting Inc. Stratus Consulting has been compensated at the time and materials hourly rate of $242 for Dr. Lipton's work and $160 for Mr. Chapman's work. Total compensation received by Stratus Consulting for the preparation of this expert report is approximately $185,000.

Dr. Rahel has been compensated at the rate $100 per hour for work done in Laramie, Wyoming, and $120 per hour for work done outside of Laramie. The total compensation for his work to date is $15,580.

Mr. Koonce is an employee of Inter-fluve, Inc. Inter-fluve has been compensated for Mr. Koonce's time at the hourly rate of $180. Total compensation received by Inter-fluve for the preparation of this expert report is approximately $15,000.

1. Introduction

The United States, including the U.S. Department of the Interior (DOI) and the U.S. Department of Agriculture (USDA), and the Coeur d'Alene Tribe (collectively, the Trustees) have undertaken a natural resource damage assessment (NRDA) to assess damages resulting from releases of hazardous substances from mining and mineral processing operations in the Coeur d'Alene River Basin, Idaho. Section 107 of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) [42 U.S.C. § 9607], Section 311 of the Clean Water Act (CWA) [33 U.S.C. § 1321], and the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) [40 C.F.R. Part 300] provide authority to the Trustees to seek such damages.

Trust aquatic resources in the Coeur d'Alene basin have been injured by releases of hazardous substances from mining and mineral processing operations. This report contains the results of natural resource damage calculations for these aquatic resources, which include surface water and the aquatic biota habitat services provided by surface water; fish, including adfluvial cutthroat trout; and other aquatic biota that rely on surface waters (benthic invertebrates, plankton, and fish).

As defined in the DOI's regulations for conducting NRDAs [43 CFR Part 11],[1] damages are "the amount of money sought by the natural resource trustee as compensation for injury, destruction, or loss of natural resources." Natural resource damage determination calculations are presented in this report for the costs of acquisition and replacement of injured natural resources [43 CFR § 11.82 (b)(ii)]. As described in Section 1.3 of this report, these acquisition and replacement costs are only one component of total damages; the costs of restoration and rehabilitation [43 CFR § 11.82 (b)(i)] are presented elsewhere, including the expert report of Ridolfi and Falter (2004).

This report follows the court's decisions regarding natural resource injury and liability resulting from hazardous substance releases from mining and mineral processing in the Coeur d'Alene River basin (U.S. District Court, 2003). It also follows the September 2000 "Report of Injury Assessment and Injury Determination: Coeur d'Alene Basin Natural Resource Damage Assessment" prepared for the Trustees by Stratus Consulting (Stratus Consulting, 2000) and other related materials presented in the Phase 1 trial (Case No. CV91-0342-N-EJL, CV96-0122-N-EJL, 2001; U.S. District Court, District of Idaho).

1. The DOI has promulgated regulations for conducting NRDAs [43 CFR Part 11]. The Trustees have relied on these regulations to the extent appropriate in assessing the natural resource damages. The application of these regulations is not mandatory, and the Trustees have the option of diverging from them as appropriate.

This report is organized as follows:

- The remainder of Chapter 1 summarizes the injuries to aquatic resources for which damages are calculated in this report (Section 1.1), describes the scope of damages addressed in this report (Section 1.2), and describes the overall approach used to calculating damages for aquatic resource injuries (Section 1.3).
- Chapter 2 presents a quantification of injured surface water. The quantification is based on analyses of exceedences of water quality criteria for the protection of aquatic life.
- Chapter 3 presents damages based on the cost of acquiring clean water as compensation for surface water contamination in the basin.
- Chapter 4 presents natural resources damages using an alternative method: the costs of replacing injured resources with resources that provide similar services[2] [43 CFR §11.82(b)(ii)].
- Chapter 5 contains literature cited in this report.
- The appendix contains resumes of the experts who authored this report.

1.1 Summary of Injury to Aquatic Resources

Trust aquatic resources of the Coeur d'Alene basin have been injured by releases of hazardous substances from mining and mineral processing operations in the basin. In Phase 1 of the trial, the court concluded the following (U.S. District Court, 2003):

- "The releases [of hazardous substances] that occurred in the Basin and continue to occur, have caused injury to natural resources in the Basin" [§ II.D.1, p. 12].
- "Leaching of hazardous materials from mining waste, including mixed tailings and alluvium in the beds and banks of the rivers and streams of the Basin, occurs whenever mining waste is exposed to elements and this creates a cycle of continuing releases of hazardous substances" [§ II.D.2, p. 12].

2. Services are defined by DOI NRDA regulations as "the physical and biological functions performed by the resource including the human uses of those functions. These services are the result of the physical, chemical, or biological quality of the resource" [43 CFR § 11.14 (nn)].

- "The co-mingled mining waste is the primary cause of the damage to natural resources in the Basin" [§ II.D.4, p. 12].

- "The testing reveals without a doubt that the exceedences in the Aquatic Life Criteria ("ALC") are continuous, regular and ongoing throughout the Basin. While some animals and fish have become acclimated to the hazardous substances in the waterways, the water quality has been injured by Defendants releases and is not recovering naturally as high water events release suspended metals" [§ III.J, p. 41].

- "Water quality criteria are exceeded for metals in the South Fork and its tributaries and this is primarily due to the metals from the tailings" [§ II.D.5, p. 12].

- "Certain fish in the Coeur D'Alene Basin, particularly the South Fork of the Coeur D'Alene River and its tributaries have not adapted so readily as other species showing some injury from the mining tailings released by the Defendants" [§ II.D.9, p. 13].

- "Benthic organisms are being exposed long-term to sediment lead and zinc concentrations found in Coeur d'Alene Lake. However, scientists disagree over whether there is any measurable injury and additional study is requested" [§ II.D.10, p. 13].

- "Due to releases of hazardous substances from mining (particularly zinc), chlorophyll levels in Coeur d'Alene Lake are not at normal levels and Coeur D'Alene Lake is potentially at risk" [§ II.D.12, p. 13].

- "While some fish have acclimated to the increased lead, cadmium, and zinc levels in the waterways, some species of fish in the waterways have clearly been injured by the hazardous substances released by Defendants" [§ III.J, p. 41].

- The Court finds Plaintiffs have carried their burden and established that some injury has occurred in both macroinvertebrates and phytoplankton" [§ III.J, p. 42].

- "Sediment concentrations of metals throughout the Basin exceed the applicable baseline" [§ II.D.7, p. 13].

- "Soil analysis and the lack of vegetation in certain parts of the Basin support this Court's finding that soils and sediments have been injured by the releases of hazardous substances by Defendants" [§ III.J, p. 41].

- "Releases of hazardous substances have flowed downstream via the tributaries of the South Fork of the Coeur D'Alene River and the Coeur D'Alene River. Such releases are flowing in Lake Coeur D'Alene and on out the lake into the Spokane River" [§ II.C.15, p. 12].

1.2 Scope of Aquatic Resources Acquisition and Replacement Damage Calculations

The damage calculations presented in this report address aquatic resources in the Coeur d'Alene basin that have been injured by the releases of hazardous substances from mining and mineral processing operations. The geographic scope includes the South Fork Coeur d'Alene River (SFCDR) downstream of its confluence with Canyon Creek; Canyon Creek and Ninemile Creek, two highly contaminated tributaries to the SFCDR; the mainstem of the Coeur d'Alene River (CDR) downstream of the confluence of the SFCDR and North Fork Coeur d'Alene River; and Lake Coeur d'Alene (Figure 1.1).

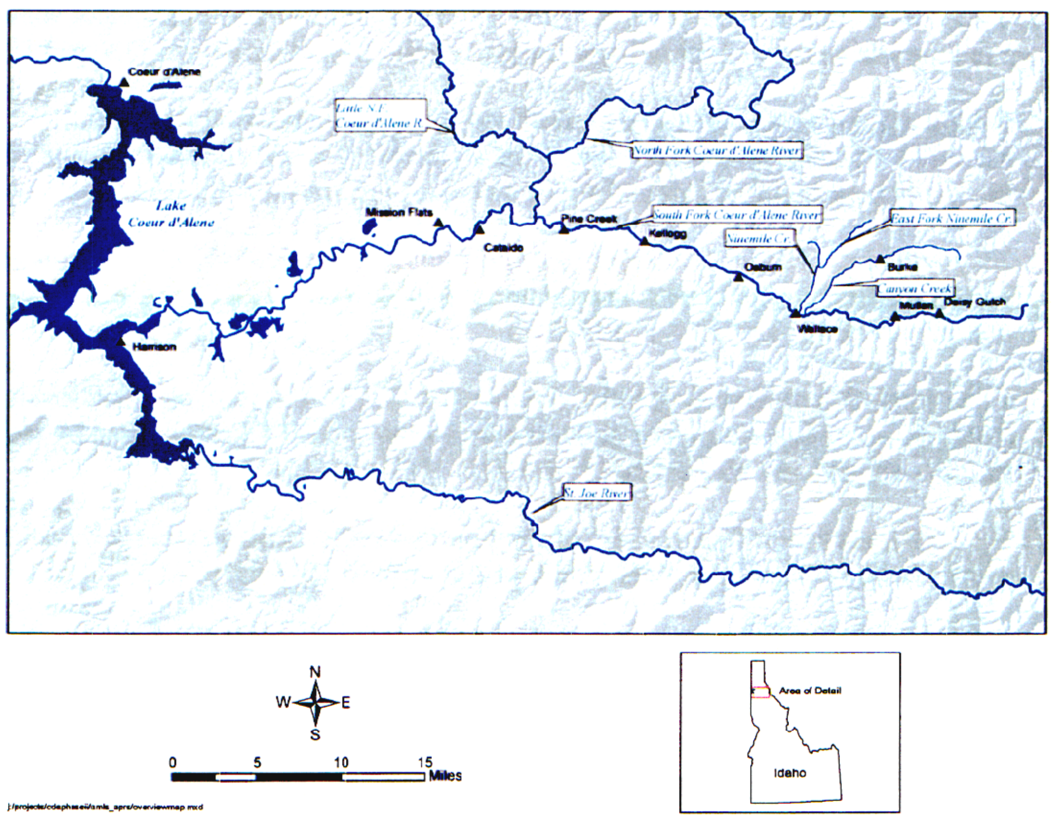


Figure 1.1. Coeur d'Alene basin showing areas addressed in aquatic resources damage calculations.

1.3 Overall Approach to Calculating Damages

The DOI regulations indicate that the measure of natural resource damages is:

> the cost of restoration, rehabilitation, replacement, and/or acquisition of the equivalent of the injured natural resources and the services those resources provide. Damages may also include, at the discretion of the authorized official, the compensable value of all or a portion of the services lost to the public for the time period from the discharge or release until the attainment of the restoration, rehabilitation, replacement, and/or acquisition of equivalent of the resources and their services to baseline[3] [43 CFR §11.80(b)].

Restoration or rehabilitation actions "are those actions undertaken to return injured resources to their baseline condition" [43 CFR § 11.82 (b)(i)]. In their expert report, Ridolfi and Falter (2004) identify and cost the actions supplemental to remedial (or "cleanup") actions being undertaken by the U.S. Environmental Protection Agency (EPA) that are necessary to eliminate sources of contamination and restore injured resources to baseline conditions.

Replacement or acquisition refers to the "substitution for injured resources with resources that provide the same or substantially similar services" [43 CFR § 11.82 (b)(ii)]. Acquisition and replacement costs are presented in this report.

Relationship of NRDA restoration to EPA remedial actions

NRDA restoration actions are distinct from EPA's response actions in the Coeur d'Alene River basin. EPA conducts response actions to address hazardous substance releases. NRDA restoration actions restore injured resources and their services to baseline. NRDA restoration must take into account any EPA response actions and evaluate whether the response actions are sufficient to restore injured resources and services to baseline. If the response actions are not sufficient to do so, then the cost of the additional NRDA restoration actions necessary to restore injured resources and services to baseline is a measure of damages [43 CFR §11.80(b)].

The EPA issued Records of Decision (RODs) for operable units (OUs) 1 and 2 of the Bunker Hill Superfund Site (the Box) in 1991 and 1992 (U.S. EPA, 1991, 1992) and an interim ROD in September 2002 for OU3 of the site (the Coeur d'Alene basin) (U.S. EPA, 2002b).[4] In addition, EPA has conducted other CERCLA response actions in the basin that are not addressed in the

3. Baseline is "the condition or conditions that would have existed at the assessment area had the . . . release of the hazardous substance under investigation not occurred" [43 CFR § 11.14 (e)].

4. The two RODs for the Box address the "Populated Areas" (also called Operable Unit 1 or OU1) and the "Unpopulated Areas" (also called OU2). The Coeur d'Alene River basin is OU3.

RODs. The EPA remedy for OU3 addresses human exposure to contaminated soils in communities and residential areas, and selected ongoing source areas and areas of ecological exposure along the creeks and rivers of the basin. Specifically, the OU3 ROD includes the following remedial actions (U.S. EPA, 2002b):

- Partial excavation of selected residential soils with high lead concentrations and other actions to reduce human exposure to lead in residential areas.
- In the upper basin, excavation and disposal, containment, bioengineering, and surface water treatment actions to reduce dissolved metals in rivers and streams. Waste dumps and stream banks that are major sources of particulate metals will be stabilized to reduce erosion.
- In the lower basin, capping and excavation of contaminated soils in selected, high-priority floodplain areas (areas with high use by waterfowl, high levels of lead in sediments, availability of site access, and relatively low potential for recontamination during flood events).
- Also in the lower basin, selected excavation of contaminated bank sediment and bank stabilization for areas that are highly susceptible to erosion.

The OU3 ROD states that the selected remedial action is "not intended to fully address contamination within the Basin" (U.S. EPA, 2002b). Thus, the selected EPA remedy will not restore injured resources to baseline, and additional NRDA restoration actions are required to do so. The environmental improvements that are anticipated after implementing actions prescribed in the OU3 ROD are accounted for in our estimate of damages (see Section 3.1).

The cost of NRDA restoration actions as the measure of damages

Injured resources and their services can be restored to baseline conditions through conducting contaminant cleanup actions supplemental to the EPA response actions, including those specified in the OU3 ROD. The cost to implement basin cleanup that supplements EPA's actions and restores resources to baseline conditions is therefore a measure of natural resource damages [43 CFR §11.80(b)].

A separate expert report prepared by Ridolfi and Falter (2004) calculates damages as the cost to conduct either a comprehensive or a staged alternative to performing contaminant cleanup actions in addition to those in the OU3 ROD to restore injured resources to baseline. In addition, the report provides cost estimates for cleanup of federal lands not addressed by the OU3 ROD, and for a management alternative that would be necessary if full restoration is not performed.

Another approach to natural resource restoration is the replacement or acquisition of the equivalent of the injured resources (43 CFR §11.82). In this case, the cost to replace or acquire the equivalent of the injured resources becomes the measure of damages. This approach to calculating damages requires a resource-by-resource analysis, which is presented in three separate reports. This report presents the costs of replacing or acquiring the equivalent of the injured aquatic resources. Separate reports calculate the cost of replacing or acquiring the equivalent of injured federal lands (LeJeune et al., 2004) and injured swans (Kern, 2004; Trost, 2004) in the basin. A summary report summarizes all of the natural resource damage calculations (Lipton et al., 2004).

2. Quantification of Surface Water Injury

This chapter quantifies surface water injuries in the Coeur d'Alene basin. The quantification is based on analyses of exceedences of water quality criteria for the protection of aquatic life, hereafter referred to as aquatic life criteria (ALC).[1]

The ALC analysis presented in the first trial included data through 1999. In this chapter, we confirm that surface water injuries have been ongoing since 1999.

2.1 Methods

Coeur d'Alene River

The methods used to determine the extent of ALC exceedence and injury for these more recent data are the same as those used previously for 1990-1999 in the Phase I trial. These methods, including methods detailing the calculation of ALC values, are described in Chapter 4 in the ROIA (Stratus Consulting, 2000).

Equations and constants used to obtain ALC values are found in the most recent EPA National Recommended Water Quality Criteria (U.S. EPA, 2002a). Magnitude of exceedence is calculated as the ratio of the measured concentration to the ALC value. If the dissolved concentration of a metal exceeds the ALC, the magnitude of exceedence is greater than 1, and the surface water is injured.

During the initial quantification of injury (Stratus Consulting, 2000), dissolved concentrations of metals in surface waters were compared to acute and chronic ALC to determine if stream reaches or locations were injured. Acute ALC are 1-hour average concentrations that are not to be exceeded more than once in a 3-year period. Chronic ALC are four-day average concentrations that are not to be exceeded more than once in a 3-year period (U.S. EPA, 1987).

1. In accordance with requirements of section 304(a)(1) of the Clean Water Act, the EPA develops, publishes, and periodically revises national recommended water quality criteria that are generally applicable to the waters of the United States. The criteria address risks to both human health and aquatic life. For the metals addressed in this report, the most stringent 304(a)(1) criteria that apply to waters of the Coeur d'Alene River basin are criteria designed to protect aquatic life.

In April 2001, the EPA revised its ambient water quality criteria and decreased the chronic and acute ALC values for cadmium [66 FR18965]. The lower ALC results in greater magnitudes of ALC exceedence compared with the 1999 cadmium criterion. To be consistent with results presented in Phase I of the trial, we compare recent water quality data to the older, less stringent ALC. Therefore, magnitudes of ALC exceedences for cadmium presented in this report are considerably lower than they would be using the revised criterion, and the degree of injury would be underestimated.

We obtained surface water data for 2000-2002 for the sites evaluated in Phase I from the U.S. Geological Survey (USGS) National Water Information System web site. We attempted to find data for Canyon Creek, Ninemile Creek, SFCDR, the lower CDR, and Lake Coeur d'Alene. We divided these into the same reaches that we used in Phase I (Stratus Consulting, 2000). Figure 2.1 shows the locations of the stream reaches, and Table 2.1 contains descriptions of the stream reaches within these areas for which post-1999 data were available. Data more recent than 2000 were not available for SFCDR-1, NM-1, and Coeur d'Alene Lake.

Table 2.1. Description of river reaches in the Coeur d'Alene basin included in ALC analysis for which post-1999 data were available

South Fork Coeur d'Alene River	
SFCDR-2	Daisy Gulch to Canyon Creek
SFCDR-3	Canyon Creek to Milo Creek
SFCDR-4	Milo Creek to Pine Creek
SFCDR-5	Pine Creek to North Fork Coeur d'Alene River
Canyon Creek	
CC-1	Headwaters to O'Neil Gulch
CC-2	O'Neil Gulch to mouth
Ninemile Creek	
NM-2	Interstate-Callahan mine to mouth
Lower Coeur d'Alene River	
CDR-1	Confluence of North and South Forks to Cataldo
CDR-2	Cataldo to Rose Lake
CDR-3	Rose Lake to Harrison

Post-1999 water quality data from the Coeur d'Alene River reaches defined above were compared to applicable ALC for dissolved cadmium, lead, and zinc.

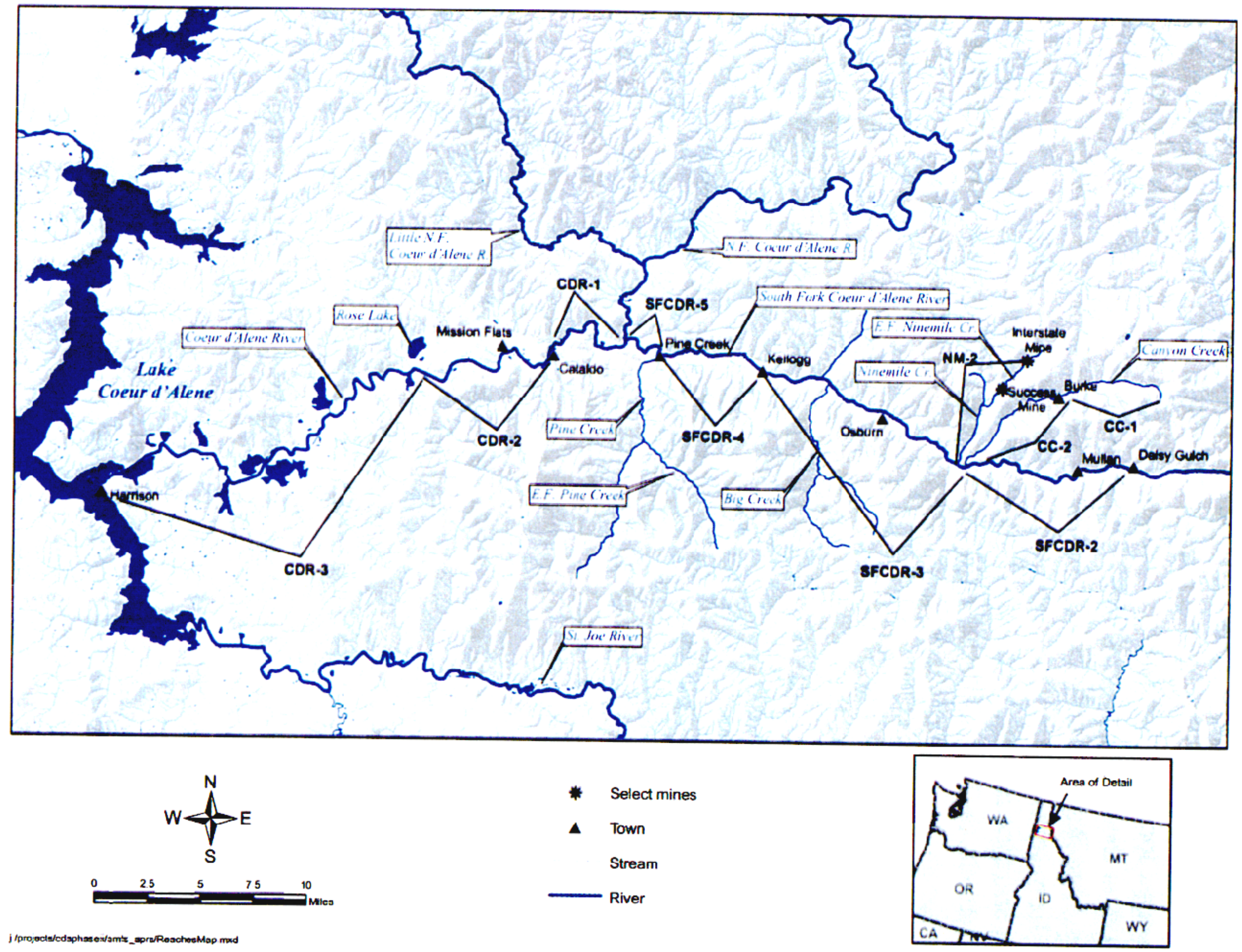


Figure 2.1. Surface water reaches in the Coeur d'Alene River basin.

Coeur d'Alene Lake

Data from sediment, surface water, benthic macroinvertebrates, and phytoplankton studies demonstrated that the lake was injured from releases of heavy metals (Stratus Consulting, 2000). Paul Woods of USGS conducted surface water sampling in Lake Coeur d'Alene during the summer and autumn of 1999 (URS Greiner and CH2M Hill, 2001a). Water samples were collected from eight locations throughout the lake: at the mouth of the St. Joe River, Blue Point (near Carey Bay), at the mouth of the Coeur d'Alene River, at University Point, at Driftwood Point, at Wolf Lodge Bay, at Tubbs Hill, and at the outlet to the Spokane River. Water samples were collected from several depths at most of these locations. Measured concentrations of cadmium, lead, and zinc in these samples were evaluated to determine if and where they exceeded ALC standards. This information was used to establish the geographic extent of injury within the lake for the purpose of the lake volume quantification calculation.

2.2 Results

Coeur d'Alene River

As indicated in the court's ruling in the first trial (U.S. District Court, 2003):

> The testing reveals without a doubt that the exceedences in the Aquatic Life Criteria ("ALC") are continuous, regular and ongoing throughout the Basin. While some animals and fish have become acclimated to the hazardous substances in the waterways, the water quality has been injured by Defendants releases and is not recovering naturally as high water events release suspended metals.
>
> Water quality criteria are exceeded for metals in the South Fork and its tributaries and this is primarily due to the metals from the tailings.
>
> Due to releases of hazardous substances from mining (particularly zinc), chlorophyll levels in Coeur d'Alene Lake are not at normal levels and Coeur d'Alene Lake is potentially at risk.

During the initial quantification of injury, dissolved concentrations of metals in surface water demonstrated significant exceedences of both acute and chronic ALC in surface waters downstream of mining disturbances (Stratus Consulting, 2000).

Creeks and rivers injured by hazardous substances in the Coeur d'Alene Basin include the South Fork Coeur d'Alene River (downstream of Daisy Gulch); the mainstem Coeur d'Alene River; Canyon Creek from Gorge Gulch to the mouth; Gorge Gulch downstream of the Hercules No. 3

adit; Ninemile Creek from the Interstate-Callahan Mine to the mouth; Grouse Gulch from the Star Mine waste rock dumps to the mouth; Milo Creek downstream of the Sullivan Adits; Portal Gulch downstream of the North Bunker Hill West Mine; Deadwood Gulch/Bunker Creek downstream of the Ontario Mill; and Government Gulch downstream of the Senator Stewart Mine. The total extent of injury within these injury stream reaches is 96.2 miles (Stratus Consulting, 2000).

Confirmation of continuing injury, 2000-2002

To investigate whether the injuries determined in Phase I have persisted in recent years, water quality data from 2000 to 2002 were compared to acute and chronic ALC. Analysis of these data indicates that exceedences of ALC continue.

Between 2000 and 2002, the SFCDR from Canyon Creek to the North Fork (SFCDR-3, SFCDR-4, and SFCDR-5) exceeded ALC for acute and chronic cadmium and zinc, and chronic lead (Table 2.2). The chronic cadmium ALC and the zinc ALC (chronic and acute ALC for zinc are nearly identical) were exceeded in all samples. The cadmium and zinc concentrations in SFCDR-4 exceeded ALCs by over 100X in at least one sample (Table 2.2). In both SFCDR-4 and SFCDR-5, the minimum measured zinc concentration exceeded the ALC by 8X (Figure 2.2).

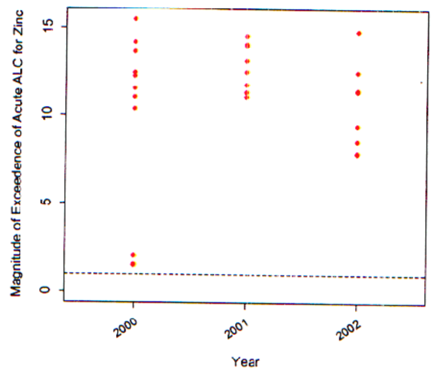
Ninemile Creek below Interstate-Callahan and Canyon Creek below Burke continue to be injured by releases of metals as well. The USGS data from 2000-2002 show exceedences of acute and chronic cadmium and zinc ALCs in all samples from those creeks (Table 2.2). The chronic lead ALC was exceeded in all samples from Canyon Creek, and in some samples from Ninemile Creek. Some samples from Canyon Creek also exceeded the acute lead ALC (Table 2.2). The maximum zinc concentration exceeded ALC by over 150X in Ninemile Creek (Figure 2.3), and by almost 100X in Canyon Creek (Figure 2.4).

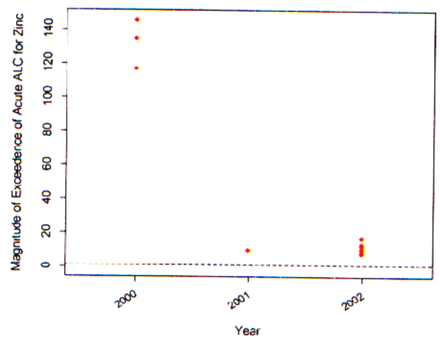
The lower reaches of the CDR, from the confluence of the North and South Forks at Cataldo to the city of Harrison, also continue to be injured by releases of cadmium, lead, and zinc (Table 2.2). In all samples from all reaches of the lower CDR, zinc concentrations exceeded ALC by at least 3X (Figure 2.5). In the middle reach (CDR-2), the chronic lead ALC was also exceeded by at least 3X in all samples. One sample in the lower reach (CDR-3) exceeded the chronic lead ALC by 93X (Table 2.2).

The 2000-2002 data indicate that the injuries determined in Phase I of the trial are still persisting. Measured dissolved concentrations continue to exceed ALC for multiple metals in SFCDR, Ninemile Creek, Canyon Creek, and the lower CDR.

Table 2.2. Range of ALC exceedences for metals in the Coeur d'Alene River basin, 2000-2002. The ALC exceedence is the ratio of the measured dissolved metal concentration to the ALC. Ratios greater than one represent injury to surface water. See Table 2.1 for description of reaches.

Reach	Metal	Acute/chronic	Minimum magnitude of exceedence	Maximum magnitude of exceedence
SFCDR-3 (Canyon Creek to Milo Creek)	Cd	Acute	0.5	3
	Cd	Chronic	2	5
	Pb	Chronic	1	10
	Zn	Both	2	15
SFCDR-4 (Milo Creek to Pine Creek)	Cd	Acute	2	139
	Cd	Chronic	2	198
	Pb	Chronic	1	16
	Zn	Both	8	146
SFCDR-5 (Pine Creek to North Fork confluence)	Cd	Acute	1	6
	Cd	Chronic	2	10
	Pb	Chronic	1	10
	Zn	Both	8	18
NM-2 (below Interstate-Callahan mine)	Cd	Acute	4	37
	Cd	Chronic	6	45
	Pb	Chronic	0.4	6
	Zn	Both	12	156
CC-2 (below O'Neil Gulch)	Cd	Acute	7	24
	Cd	Chronic	8	26
	Pb	Acute	0.4	3
	Pb	Chronic	11	79
	Zn	Both	25	96
CDR-1 (SF/NF confluence to Cataldo)	Cd	Acute	0.7	2
	Cd	Chronic	0.8	2
	Pb	Chronic	1	7
	Zn	Both	3	7
CDR-2 (Cataldo to Rose Lake)	Cd	Acute	1	2
	Cd	Chronic	1.6	2
	Pb	Chronic	3	8
	Zn	Both	5	7
CDR-3 (Rose Lake to Harrison)	Cd	Acute	0.3	2
	Cd	Chronic	0.5	2
	Pb	Acute	--	4
	Pb	Chronic	1	93
	Zn	Both	3	8





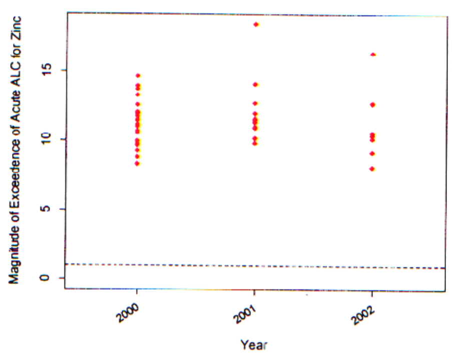


Figure 2.2. Magnitude of exceedence of the acute ALC for zinc in 2000-2002 data in the South Fork Coeur d'Alene River reach SFCDR-3 (top), SFCDR-4 (middle), and SFCDR-5 (bottom). Exceedence values greater than 1 (dotted horizontal line) indicate injury.

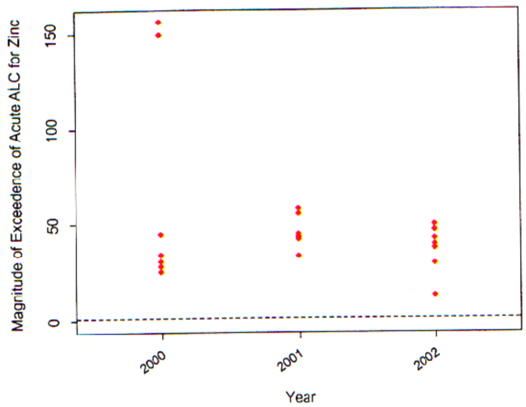


Figure 2.3. Magnitude of exceedence of the acute ALC for zinc in 2000-2002 data in Ninemile Creek reach NM-2. Exceedence values greater than 1 (dotted horizontal line) indicate injury.

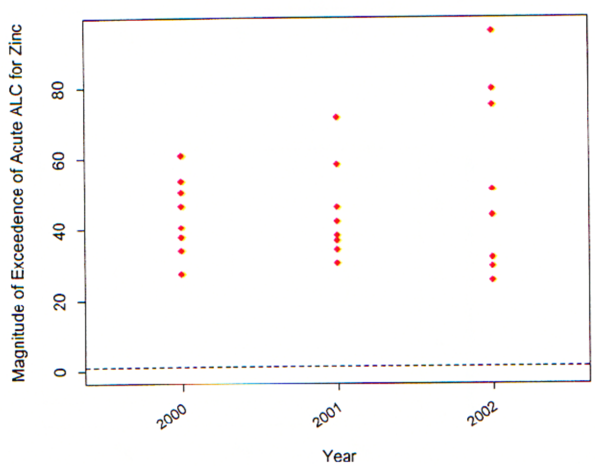


Figure 2.4. Magnitude of exceedence of the acute ALC for zinc in 2000-2002 data in Canyon Creek reach CC-2. Exceedence values greater than 1 (dotted horizontal line) indicate injury.

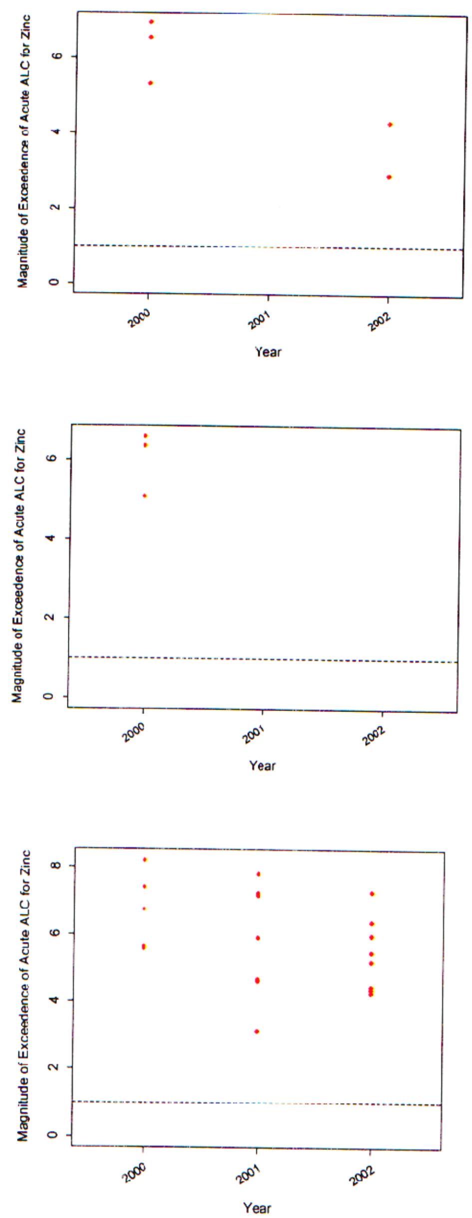


Figure 2.5. Magnitude of exceedence of the acute ALC for zinc in 2000-2002 data in the Lower Coeur d'Alene River reach CDR-1 (top), CDR-2 (center), and CDR-3 (bottom). Exceedence values greater than 1 (dotted horizontal line) indicate injury.

Coeur d'Alene Lake

USGS collected data from at eight stations and multiple depths throughout the lake in 1999. We compared these data to acute and chronic ALC values for dissolved cadmium, lead, and zinc.

Acute and chronic ALC values for dissolved zinc were exceeded at all stations from the Spokane River outlet southward to Blue Point. All sampling locations demonstrated ALC exceedences at multiple depths. The one sample collected at the mouth of the St. Joe River did not exceed the ALC criterion. Zinc concentrations exceeded ALC by up to 3X at locations from Blue Point northward.

Chronic lead ALC were exceeded at all locations from the mouth of the Coeur d'Alene River northward to the outlet of Lake Coeur d'Alene at the Spokane River, except for Wolf Lodge Bay. At least one sampling depth demonstrated an exceedence at these locations. The maximum lead concentration exceeded the chronic ALC by 9X.

Sampling locations south of the Coeur d'Alene River, at Blue Point and at the mouth of the St. Joe River, did not exceed the chronic lead criterion. The acute lead criterion was not exceeded at any locations throughout the lake. Chronic and acute cadmium values were less than ALC at all locations and all depths throughout the lake.

Thus, the 1999 lake sampling data indicate that Lake Coeur d'Alene surface water exceeds the zinc ALC and the chronic lead ALC in locations from Blue Point northward.

3. Acquisition of Clean Water

This section presents the calculation of the costs of acquiring clean water as compensation for injured surface water [43 CFR § 11.82 (b)(ii)]. The acquisition cost is the purchase price of clean water needed to replace the water injured by releases of hazardous substances. The calculation of the volume of injured water is presented in Section 3.1, and the estimation of the cost of water is presented in Section 3.2. The cost of acquiring clean water as compensation for the injured water is presented in Section 3.3.

3.1 Quantification of the Volume of Injured Water

The court ruled that surface water data indicated "the exceedences in the Aquatic Life Criteria ('ALC') are continuous, regular, and ongoing throughout the basin" (U.S. District Court, 2003). We quantified the volume of injured surface water as the annual volume of the Coeur d'Alene River inflow into Lake Coeur d'Alene.

Volumetric data were obtained from USGS gauging station #12413500 located on the Coeur d'Alene River near Cataldo. The station was chosen because:

- The Cataldo data set is comprehensive and allows for the calculation of a reliable estimate of yearly flow. The data record for Cataldo provided daily flow data from 1911 to 2002, with the exception of 1913-1919 and 1973-1985.

- The Cataldo gauging station is close enough to the delta that the volume of the river is not significantly increased by tributary contributions before reaching Coeur d'Alene Lake. The Cataldo station is also far enough upstream from the lake that it is not affected by backflow from the lake.

Using the daily flow data, we calculated the total flow volume for each year (Figure 3.1), and then averaged the across the years of data. The average annual flow in the Coeur d'Alene River is 2,526 cubic feet per second, or approximately 1.8 million acre-feet (AF) per year. For reference, 1.8 million AF of water would submerge the entire state of Rhode Island over 2.5 feet deep.[1]

1. Rhode Island is 1,045 square miles (U.S. Bureau of the Census, 2004). One square mile = 640 acres.

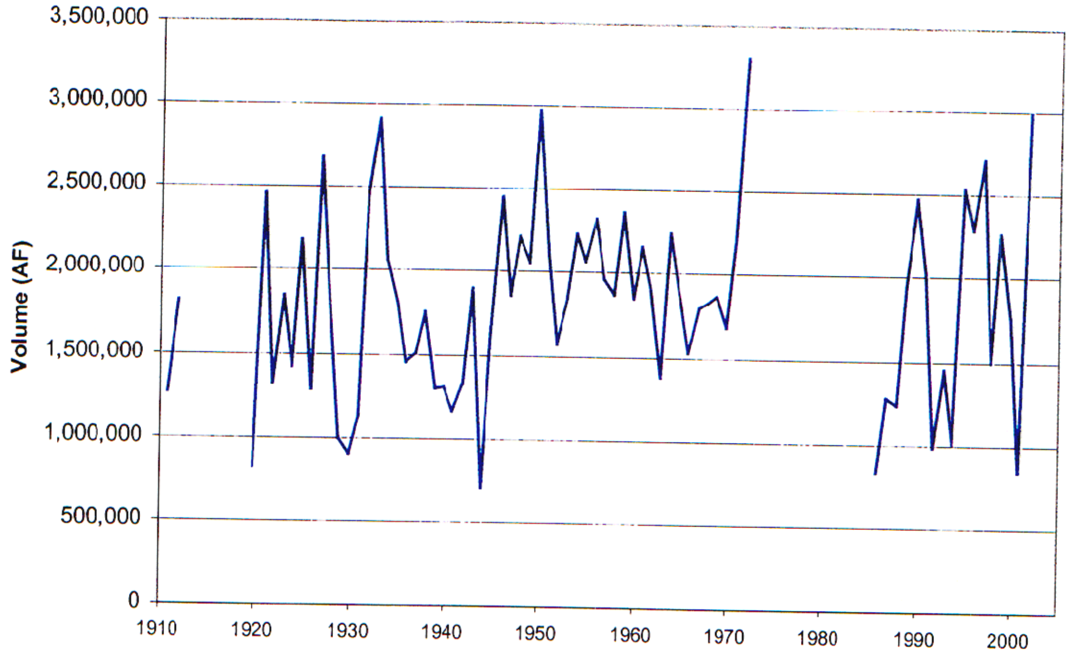


Figure 3.1. Average annual inflow from the Coeur d'Alene River: 1911-2002.

3.2 Estimation of the Cost of Water

3.2.1 Approach

We estimated acquisition costs as the price of permanent water rights and as the price of leasing water rights over time. To determine the cost to purchase permanent water rights or lease water rights over a given period, we compiled information on water sales and leases in Idaho. We relied on historical water sales and lease transactions as reported in two publications: The Water Strategist (1999-2003) and "The Sale and Leasing of Water Rights in the Western United States: An Overview for the Period 1990-2001" (Czetwertynski, 2002). The Water Strategist is the industry leader in reporting sales and lease transactions in the western United States. "The Sales and Leasing of Water Rights in the Western United States" uses information from the Water Strategist and other state and local information to develop a thorough historical database on water right purchases and water leasing in the western United States.

In addition, we contacted water managers and other knowledgeable individuals to verify facts and provide supporting information. Individuals contacted include:

- Paul Baker, manager, East Greenacres Irrigation District
- Cynthia Clark, associate engineer, Water Allocation Bureau of the Idaho Department of Water Resources (IDWR)
- Zena Cook, resource economist, Water Planning Bureau of the IDWR
- Glen Saxon, administrator of the Water Management Division of the IDWR
- Ron Shurtleff, water master, Water District 65
- Lee Sisco, water master, Water District 63.

We considered two approaches for estimating the cost of acquiring water:

- the cost to purchase water rights in Idaho
- the cost to lease or rent water in Idaho.

The better estimator is the cost to purchase permanent water rights because permanent water loss due to contamination should be offset with the purchase of a permanent water right. However, the number of water rights sales in the Coeur d'Alene region is small, so the uncertainty of the estimate is high. In addition, the volume of water required to compensate for lost water service flows is much larger than any single historical water rights sale.

More information is available on leasing water. In Idaho, the Idaho Water Resource Board (the Board) manages the Idaho Water Supply Bank (the Bank). The Bank is a water exchange market for natural flow (surface water diverted from a river, stream, or groundwater) and stored water (water stored in a reservoir). Water users who have more water or more rights to water than they require can put the excess in the Bank. Water in the Bank can be leased to people who do not have enough to meet their needs.

In the Bank, stored water is water held in "rental pools" in reservoirs in Idaho. The four main rental pools in Idaho are operated by local committees appointed by the Board. The rental pool committees set the price of water rental, and the Board approves the price. The price differs by rental pool and can depend on where the water is to be used (IDWR, 2004). The Board directly controls the sale or lease of natural flow (Cynthia Clark, Water Allocation Bureau of the IDWR, personal communication, May 13, 2004).

An additional source of leasing information is Bureau of Reclamation (BOR). The BOR leases 427,000 AF of water per year in Idaho for maintenance of minimum instream flows (environmental flows) required by the Water Planning Bureau of the IDWR.

3.2.2 Purchase prices

Three water rights transactions have been reported since 1990: a surface water right purchase in 1996, and two groundwater right purchases in 1999. The single surface water right sold for irrigation use at $169 per AF. In 2004 dollars, the average of the reported transactions for permanent rights to 1 AF of water was approximately $221.

3.2.3 Lease prices

Water lease records indicate 63 lease agreements between 1990 and 2003 (Water Strategist, 1999-2003; Czetwertynski, 2002). Using the lease agreement prices, we estimated an average price for 1 AF of water between 1990 and 2003 using all 63 lease agreement prices, and using only prices for water leased for irrigation use.

The average of all 63 reported lease prices from 1990 to 2003 is $10.44 per AF (Table 3.1). The data on which the average is based include both natural flow and rental pool agreements. The Board typically leases natural flow waters at $11 per AF (Cynthia Clark, Water Allocation Bureau of the IDWR, personal communication, May 13, 2004). The water leased through the four rental pools is typically priced between $3 and $10 per AF (Glen Saxon, Water Management Division of the IDWR, personal communication, May 14, 2004), but lease prices can be more variable:

- Water District 1 (Snake River Basin) rents pool water for use above Milner Dam at $9.60 per AF. Water for use as flow augmentation below Milner Dam is leased at $14.55 per AF for the first 100,000 AF and $22.80 per AF for all water in excess of 100,000 AF (IDWR, 2004).

- Water District 63 (Boise River Basin) rents water for use in the basin at $6.50 per AF, and for use out of basin at $6.90 per AF (Lee Sisco, Water District 63, personal communication, July 20, 2004).

- Water District 65 (Payette River Basin) rents water for use in the basin at $3.20 per AF, and for use out of basin at $8.50 per AF (Ron Shurtleff, Water District 65, personal communication, July 19, 2004).

- Water District 65K (Payette River Basin on Lake Fork Creek) rents water for use upstream of the mouth of Lake Fork Creek at $2.70 per AF (IDWR, 2004).

Table 3.1. Lease and rental prices for water in Idaho ($ per AF in 2004 dollars)

Price description	Price per AF
Average of all identified water lease and rental prices	$10.44
Average of water lease prices for agricultural use	$5.74
East Greenacres Irrigation District (for up to 2.5 AF per acre)	$10.00
Idaho Water Supply Bank, natural flow water	$11.00
Water District #1 (price for use above Milner Dam) Water District #1 (price for use below Milner Dam)	$9.60 $14.55 to $22.80
Water District 63 (average of in and out of basin use prices)	$6.70
Water District 65 (average of in and out of basin use prices)	$5.85
Water District 65K (for use upstream from the mouth of Lake Fork Creek)	$2.70
BOR (for direct diversions off the Snake River)	$50.00

The rental pools operate exclusively in the more arid southern and central parts of Idaho, and in arid regions of the western United States, water prices often reflect the relative scarcity of the resource. To evaluate whether a water price that reflects, in part, the price of water in southern and central Idaho is reasonable for northern Idaho, we investigated lease prices by East Greenacres Irrigation District near Coeur d'Alene.

East Greenacres Irrigation District leases water for irrigation use at $10 per AF for the first 2.4 AF for each acre (Paul Baker, East Greenacres Irrigation District, personal communication, May 26, 2004). If consumption reaches or exceeds 2.5 AF per acre, the price for the additional water is $12 per AF. Therefore, the lease value based on the 63 records that include data from southern and central Idaho are consistent with current lease prices in northern Idaho, and with the natural flow lease price set by the Board (Table 3.1).

In Idaho, reported lease prices for agricultural water are typically lower than lease prices for commercial, municipal, and industrial water. The average lease price of irrigation water is therefore a lower bound estimate of the cost of water in Idaho. The average price of water leased for irrigation use was $5.74 per AF. The water prices set by two of the rental pools (Water District 63 and Water District 65) are similar to the calculated average agricultural price of leased water (Table 3.1).

The BOR leases 427,000 AF of water per year in Idaho for flow augmentation. BOR has been paying farmers a negotiated lease price of $150 per acre per year of land left idle (Cynthia Clark, Water Allocation Bureau of the IDWR, personal communication, May 13, 2004). Resting one acre of land frees about 3 AF per year of irrigation water in this region, so BOR pays approximately $50 per AF per year (Cynthia Clark, Water Allocation Bureau of the IDWR, personal communication, May 13, 2004). BOR makes the $50 lease arrangement only with individuals who have rights for direct diversion from the Snake River. BOR also acquires water from rental pools to meet its annual need (Cynthia Clark, Water Allocation Bureau of the IDWR, personal communication, June 6, 2004).

3.3 Cost of Acquisition of Clean Water

3.3.1 Cost of acquiring clean water by purchasing water rights

Using the average purchase price for the three water right purchases (Section 3.2.2), we estimated the amount of money necessary in 2004 dollars to acquire permanent water rights to replace the injured water (1.8 million AF per year).

To acquire that much water, we assumed that each year for 10 years, rights to 182,877 AF of water are purchased. At the end of the 10-year period, permanent rights to 1,828,768 AF of water would have been obtained. We assumed a constant price of water rights (i.e., the real price of water increases 0% from 2005 to 2014) and an inflation rate of 2.2%.[2] While it is likely that the real price of water rights would increase over the 10-year period, the assumption of a constant price of water rights makes ours a lower bound estimate of the total amount of money needed to purchase the necessary rights.

We assumed that on January 1, 2005, a lump sum is invested in the DOI Natural Resource Damage Assessment and Restoration Fund (NRDARF), which earns a specified rate of return based on yields of U.S. Treasury notes.[3] The NRDARF invests in multiple treasury instruments to meet the expected time flow of money required by the natural resource trustees. Currently the yield for treasury securities of maturation between 6 months and 10 years averages 3.23% (U.S. Treasury real yield curve rate, July 28, 2004).

Using $169 per AF as the purchase price, the estimated funds needed to be received on January 1, 2005, to purchase the needed water over a 10-year period is $302.7 million (2004 dollars) (Table 3.2). Using the overall average of $221 per AF price, the necessary amount is $394.3 million (2004 dollars). After the tenth year, the funds from the account would be

2. The 2004 President's Budget assumes 2.2% annual inflation through 2008 for projections (U.S. Congress, 2004).

3. Funds recovered by natural resource trustees can be placed into the DOI NRDARF Fund. The DOI fund invests deposits in U.S. Treasury Securities and does not charge account holders fees for fund management. Thus all principal and interest is available for future use (Bruce Nesslage, DOI funds manager, personal communication, August 4, 2004).

Table 3.2. 10-year purchase plan for acquisition of clean water

Funds needed in 2005 at $169 per AF (millions of dollars)	$302.7
Funds needed in 2005 at $221 per AF (millions of dollars)	$394.3
Date first purchase made	January 1, 2005
Date last purchase made	January 1, 2014
Volume of each purchase (AF)	182,877
Real price increase of water	0%
Yield on investment	3.23%

exhausted and water rights would have been secured for the volume of water equal to the annual Coeur d'Alene River flow.

3.3.2 Cost of acquiring clean water by leasing

We used three lease prices (described in Section 3.2.3) to calculate the amount of money necessary in 2004 dollars to replace the 1.8 million AF per year of injured water:

- $5.74 – the average of identified lease prices for agricultural use from The Water Strategist (1999-2003) and Czetwertynski (2002)
- $10.44 – the average of identified lease prices from The Water Strategist (1999-2003) and Czetwertynski (2002)
- $50.00 – the average price the BOR pays in the region to lease water for environmental flows.

We calculated the funds needed today (2004) to lease 1.8 million AF of water annually. We calculated the cost of leasing water for 30 years (2005-2034), for 50 years (2005-2054), and for 100 years (2005-2104). EPA's ROD for OU3 (the Coeur d'Alene basin) estimates that downstream transport of metals above water quality criteria will continue well into the foreseeable future (U.S. EPA, 2002b). Since injuries to surface water are anticipated to continue for the foreseeable future, the 100 year scenario is the most appropriate estimate. Again, we conservatively assumed that the real increase in the price of water is 0% and that the inflation rate is 2.2%. The base year for present value calculations was 2004.

We assumed that on January 1, 2005, funds will be available to invest into U.S. Treasury bonds so that at the time of bond maturity, the bond value plus accumulated interest would be equal to the price of the lease for that year. The rate returns were based on yields of U.S. Treasury notes provided by the U.S. Treasury Department, and extrapolated up to 30 years into the future.[4] This method of extrapolation is consistent with the U.S. Treasury's method for estimating long-term yields. For bonds with maturities greater than 30 years, the 30-year yield was used.

Table 3.3 presents the amount of money needed for investment to provide the annual flow of funds sufficient to lease water each year for the 30-, 50-, and 100-year scenarios. At the end of the time period for each scenario, the total sum of funds will have been exhausted.

Table 3.3. Funds needed in 2004 to lease 1.8 million AF of water per year based on three lease price estimates (all scenario prices in millions of 2004 dollars)

Scenario	Lease period	Price per AF ($5.74)	Price per AF ($10.44)	Price per AF ($50.00)
30-year scenario	2005-2034	$212.8	$406.2	$1,945.4
50-year scenario	2005-2054	$273.8	$522.6	$2,503.1
100-year scenario	2005-2014	$329.8	$629.4	$3,014.2

3.3.3 Summary

Because the water of the Coeur d'Alene River will continue to be injured for the foreseeable future, the most relevant acquisition cost estimates are for purchase of water rights and 100-year leases. The agricultural water rights ($169 per AF) and the agricultural water leases ($5.47 per AF) are most relevant compensation for the type of water lost. At these prices, the acquisition costs for injured surface water range from $302.7 million to $329.8 million (2004 dollars).

4. Linear extrapolation factors, as determined by the Office of Debt Management, are determined by considering the slope of the yield curve at its long end and extrapolating to a theoretical 30-year point. To use the extrapolation factor to determine a 30-year proxy rate, add the factor to the 20-year constant maturity rate. For example, if on a particular day the 20-year constant maturity is 5.40% and the extrapolation factor is 0.02%, then a 30-year theoretical rate would be 5.40% + 0.02% = 5.42% (U.S. Treasury, 2004).

4. Replacement of Services

This chapter presents an analysis of the costs of replacing the natural resource services lost because of the injuries with similar services. The replacement costs of services are different than the cost of acquisition of clean water (Chapter 3): here, the replacement cost method is focused on replacing similar *services* to those that have been lost as a result of natural resource injuries. The services addressed in this replacement analysis are the ability of surface water to provide supporting habitat to aquatic biota, particularly fish. Injuries to surface water included both exceedences of water quality criteria for the protection of aquatic life and injuries to fish.[1] In addition, fish themselves have been injured (U.S. District Court, 2003), including both resident and adfluvial trout. As a result, alternatives designed to provide replacement surface water habitat for fish services provide an appropriate means of calculating replacement costs for both surface water and aquatic biota services, and those replacement costs are a measure of natural resource damages to aquatic resources.

Replacement of the lost surface water/biota services can be accomplished by performing actions that enhance surface water habitats and thereby benefit fisheries in the Coeur d'Alene region. Replacement of "substantially similar services" [43 CFR §11.82 (b)(ii)] is accomplished by providing surface water habitat enhancements in the vicinity of the Coeur d'Alene basin that benefit the types of waterways and habitats that have been injured, and by performing actions that enhance surface water habitats that support spawning, rearing, and adult fisheries, as well as other aquatic biota.[2] Service gains from habitat enhancement can be scaled against habitat service losses from the injuries using trout population density as the scaling metric.

Because trout population density was the metric with which replacement habitat was quantified, the spatial scope of the service replacement analysis presented here is limited to the upper Coeur d'Alene Basin, including the SFCDR from its confluence with Canyon Creek to its confluence with the North Fork CDR, Canyon Creek, and Ninemile Creek. Data limitations regarding fish

1. U.S. District Court, 2003. Definitions of injury to surface water resources in the DOI regulations include "concentrations and duration of substances in excess of applicable water quality criteria . . ." [43 CFR § 11.62 (b)(iii)] and "concentrations and duration of substances sufficient to have caused injury . . . to . . . biological resources, when exposed to surface water, suspended sediments, or bed, bank, or shoreline sediments" [43 CFR §11.62 (b)(v)].

2. For example, projects that simply involved provision of fish – for example, providing free fish in local markets, providing additional stocking of hatchery fish, or supplementing fisheries with extremely metal-tolerant species such as carp – would not provide the same services, either ecological or human-related, as a natural fishery that supports native species and all appropriate age-classes or the overall ecological services provided by surface water habitats.

population densities in the CDR downstream of the North Fork-South Fork confluence (including in the mainstem river and in the lateral lakes) made quantification of service losses in this reach problematic and, as a result, this injured area was excluded from the analysis presented here. It should be emphasized, however, that surface waters in these areas of the lower basin, including the lake, are injured (see Chapters 2 and 3), and aquatic biota services – including for both resident species and adfluvial cutthroat trout – most probably have been lost. As a result, the replacement analysis we present here must be viewed as an underestimate of natural resource damages. Work is ongoing to evaluate potential service replacement damages in the lower basin (including the lake), and we reserve the right to supplement our opinions.

The replacement cost analysis presented in this section contains several discrete steps. First, the aquatic services that have been lost are quantified (Section 4.1). This quantification involves calculating the amount of services lost relative to baseline conditions, as measured by changes in trout population density, incorporating the anticipated improvements from implementation of EPA's remediation actions. Next, regionally appropriate replacement alternatives are identified and discussed (Sections 4.2.1-4.2.4). These alternatives consist of actions that could be undertaken in the region which would provide beneficial enhancements to regional fisheries. The anticipated benefits of the projects, in terms of fishery improvements, are also evaluated. Next, project feasibility is discussed (Section 4.2.5) and the costs of implementing these alternatives is calculated based on representative unit and project costs (Section 4.2.6). Finally, the total replacement cost is calculating by scaling the amount of replacement to the quantity of injury (Section 4.3). This scaling accounts for both the loss relative to baseline and supplemental replacement necessary to compensate for the "services lost to the public for the time period from the . . . release until the attainment of the restoration . . . to baseline" [43 CFR § 11.80 (b)].

4.1 Quantification

Chapter 2 quantified the injury to surface water resources. However, as noted above, surface water service losses are quantified for the service replacement analysis using trout population densities as a scaling metric. This section quantifies those service losses, as measured by reductions in trout population densities relative to baseline conditions. Lost services are quantified for injured surface waters of Canyon Creek, Ninemile Creek, and the SFCDR downstream of Canyon Creek.[3] Much of these data were presented in the ROIA (Stratus Consulting, 2000) and subsequently admitted as evidence in Phase I of the NRDA litigation.

3. As noted previously, because of data limitations, the service replacement analysis excludes the lower Coeur d'Alene basin, including the mainstem CDR (downstream of the North Fork confluence), the lateral lakes, and Lake Coeur d'Alene. As a result, the quantification of lost services presented here most probably underestimates total losses of surface water services.

4.1.1 Methods

To use trout densities as a metric for lost surface water services, we first quantified the trout densities in the injured reaches of the Coeur d'Alene basin. We subsequently compared these densities to baseline trout densities to determine the overall loss. Although multiple species of fish in addition to trout have been injured by releases of hazardous substances (Stratus Consulting, 2000), we focused our quantification on trout services because 1) there are more data available to quantify trout densities than other species, and 2) trout provide important services both to the ecosystem and to humans. Nonetheless, by focusing this quantification solely on trout, we are underestimating the total loss of fish in the injured stream reaches.

The Report of Injury Assessment and Determination (Stratus Consulting, 2000) presents fish population data from R2 Resource Consultants (1995, 1996, 1997; Reiser et al., 1999) and Stratus Consulting (1999). These were used to compute service loss. We used data from multiple pass depletion (MPD) electrofishing for our population estimates, unless single pass data were the data available.

For baseline fish populations in the SFCDR, we used average trout densities in the SFCDR upstream of the Canyon Creek, as presented in the first trial. We used trout densities in Canyon Creek upstream of Burke as the baseline for fish populations in Canyon Creek. The Stratus Consulting and R2 data from the ROIA (Stratus Consulting, 2000) did not contain baseline trout densities for Ninemile Creek; therefore, we used Idaho DEQ single pass electrofishing data (Idaho DEQ, 2002) to estimate baseline densities in Ninemile Creek. These baseline areas are not pristine environments and likely have reduced trout populations relative to locations without any human disturbance.

To determine service loss, we compared the difference in trout density between the injured and baseline conditions. We also calculated the total area of injured streams by multiplying stream length by average stream width. The average stream width for a given segment came from Stratus Consulting (1999) and R2 Resource Consultants (1995, 1997) field data. Stream lengths were calculated by GIS using the centerline of each stream reach. Table 4.1 describes the stream reaches and shows the calculated length and average width of each reach.

The high resolution stream network used in Phase 1 of the trial was again used here as the basis for the calculations on all reaches except the SFCDR from the mouth of Canyon Creek to the confluence with the North Fork. The Phase I stream network contained only shoreline data for this reach; the high-resolution National Hydrographic Dataset (NHD) of streams (USGS, 2002) allowed us to calculate stream length using the centerline. In the SFCDR, we calculated average wetted stream widths for each reach by 5-mile stream segment (rounded to nearest mile). We had

Table 4.1. Calculated lengths and average widths for injured stream reaches in the SFCDR basin

Reach description	Approximate river mile	Average wetted width (m)[a]	Reach length (m)
SFCDR: Daisy Gulch to Canyon Creek	From RM 30 to RM 20 (from confluence with North Fork)	6.25	15,186.34
SFCDR: Canyon Creek to the North Fork confluence	From RM 20 to RM 0 (from confluence with North Fork)	14.18	32,576.33
Ninemile Creek (East Fork): Interstate Mill-Callahan to Success	From RM 6.3 to RM 4.5[b] (from mouth of Ninemile Creek)	3.14	3,032.04
Ninemile Creek (mainstem and East Fork): Success to SFCDR confluence	From RM 4.5 to RM 0[b] (from mouth of Ninemile Creek)	3.52	7,201.44
Canyon Creek: approximately Burke to the mouth	From RM 6.4 to RM 0 (from mouth of Canyon Creek)	7.96	10,335.15

a. Averages calculated for each by 5-mile increment (rounded to nearest mile), then averaged again over entire reach.
b. Mainstem Ninemile Creek from RM 0 to 3, then East Fork Ninemile Creek above RM 3.

between two and six width measurements per segment. After finding the average for each 5-mile segment, we then took the mean of those averages to determine the average width of the entire reach in question.

The calculation of reduced trout densities provides a quantification of service loss at one particular time. To fully calculate service loss, we also incorporated the interim loss by accounting for the amount of time that the service is lost, i.e., the number of years in which the surface waters have been and will continue to be injured.

The interim loss calculations for future services consider and incorporate the effects of EPA's remediation. The ROD (U.S. EPA, 2002b) and the Technical Memorandum on Interim Fisheries Benchmarks (URS Greiner and CH2M Hill, 2001b) provide anticipated improvements to the mining-impacted areas over a 30-year time span. We compared current trout densities with anticipated densities in 30 years assuming the interim benchmarks will be reached. This provides an estimate of the recovery of the lost fishery services over time.

The interim benchmarks for the injured streams are grouped into broad categories, or "tiers," based on anticipated ranges of ALC exceedences and approximate fish densities. For example, if the interim goal is to establish a Tier 2 fishery, the target concentrations of zinc would be 7-10X higher than the chronic ALC, and trout populations would be <0.05 fish/m^2 (URS Greiner and CH2M Hill, 2001b).

To more precisely estimate future trout densities based on benchmark zinc concentrations in the surface water, we plotted the magnitude of ALC exceedences in injured areas against the percent reduction in trout density compared to baseline. We established a relationship between trout density and the magnitude of ALC exceedence. Using SFCDR data presented in the ROIA (Stratus Consulting, 2000), we paired fish density data with water chemistry samples. Chemistry data for the location closest to the fish population survey data were used when possible; otherwise, the mean chemistry value for the entire reach was used. In most cases chemistry data were from within 0.5 miles of the fish survey location.

To better define the relationship between trout density and the magnitude of zinc ALC exceedence, we also included paired fish density and zinc data from Pine Creek downstream of the Constitution Mine (McNary et al., 1995). We also used data from Canyon Creek downstream of Burke, where the fish density is 0. For magnitude of exceedence, we used the average Canyon Creek ALC exceedence in 1998 (Stratus Consulting, 2000).

4.1.2 Results

Baseline trout populations

R2 Resource Consultants (1995, 1996) performed MPD electrofishing near the headwaters of Canyon Creek, upstream from Burke, in 1994 and 1995. Trout densities were 0.08 and 0.03 trout/m^2, respectively, for an average trout density of 0.055 trout/m^2 (Table 4.2). Relative to other headwater streams in the basin, this is a low trout density (Stratus Consulting, 2000). This is a conservative estimate of the baseline trout density in Canyon Creek, because the lower the baseline density, the smaller the service loss.

R2 Resource Consultants (1995, 1996) performed MPD electrofishing near the headwaters of East Fork Ninemile Creek and found no fish. However, using single pass electrofishing in 1995 and in 2002, the Idaho DEQ (2002) found cutthroat trout in both East Fork Ninemile Creek above Interstate-Callahan and the headwaters of the mainstem Ninemile above the East Fork confluence (Table 4.2). The average trout density in the upper East Fork was 0.122 trout/m^2, and the average density in the upper mainstem was 0.371 trout/m^2 (Table 4.2). These are conservative estimates of the trout densities in these reaches because we assumed 100% capture efficiency using only one pass. According to URS Greiner and CH2M Hill (2001b), the capture efficiency is more likely to be less than 50%, in which case we are underestimating baseline trout densities by at least a factor of two (and, as a result, underestimating service loss).

Table 4.2. Trout density data from Canyon and Ninemile creeks[a]

Reach description	Approximate river mile	Year	Estimated trout density (#/m^2)
Canyon Creek near headwaters	8	1994	0.080
Canyon Creek near headwaters	8	1995	0.030
Upper Canyon Creek average			*0.055*
Canyon Creek near mouth	0.5	1995	0
Lower Canyon Creek average			*0*
East Fork Ninemile Creek above Interstate-Callahan	6.5[b,c]	1995	0.137
East Fork Ninemile Creek above Interstate-Callahan	6.5[b,c]	2002	0.107
Upper East Fork Ninemile Creek average			*0.122*
Mainstem Ninemile Creek above East Fork confluence	3.33[b,c]	1995	0.243
Mainstem Ninemile Creek above East Fork confluence	3.26[b,c]	1995	0.500
Upper Mainstem Ninemile Creek average			*0.371*
East Fork Ninemile Creek below Interstate-Callahan	4.0[b]	1995	0
Mainstem Ninemile Creek below East Fork confluence	2.5	1994	0
Mainstem Ninemile Creek below East Fork confluence	2.5	1994	0
Ninemile Creek average			*0*

a. All density data included herein are derived from MPD electrofishing data unless otherwise noted. Sources: R2 Resource Consultants (1995, 1996, 1997); Reiser et al. (1999); Stratus Consulting (1999).
b. Measured from the confluence of Ninemile Creek and the SFCDR. The confluence of the mainstem Ninemile and the East Fork is at RM 3.06.
c. Single-pass electrofishing data from IDEQ BURP program (Idaho DEQ, 2002). We assume 100% capture efficiency to be sure not to overestimate baseline trout density.

We used the average density of the East Fork headwater sites (0.122 trout/m^2) as our baseline trout density for quantifying service losses to Ninemile Creek. The average density in the upper mainstem Ninemile Creek above the East Fork confluence was three times higher (0.371 trout/m^2). While it would be reasonable to consider the upper mainstem density to be the baseline density for the rest of the mainstem, we used the lower density from the upper East Fork to be conservative.

For the SFCDR baseline, we used an average trout density from several upstream SFCDR sites. R2 Resource Consultants (1995, 1996, 1997; Reiser et al., 1999) and Stratus Consulting (1999) collected fish population data from the SFCDR upstream of Canyon Creek. Between 1994 and 1998, a total of 10 MPD analyses were performed at five different upstream locations (Table 4.3). The mean trout density was 0.118 trout/m^2.

Table 4.3. Trout density data from the SFCDR[a]

Reach description	Approximate river mile	Year	Estimated trout density (#/m^2)
Upper locations			
SFCDR near headwaters	32.7	1994	0.087
SFCDR near headwaters	32.7	1995	0.081
SFCDR near headwaters	32.7	1996	0.034
SFCDR near Hwy Dept	28	1995	0.153
SFCDR near Hwy Dept	28	1998	0.071
SFCDR near Mullan	26.7	1994	0.204
SFCDR near Mullan	26.7	1998	0.185
SFCDR near Compressor	24.1	1996	0.080
SFCDR near Golconda	22.5	1994	0.172
SFCDR near Golconda	22.5	1995	0.111
Upper SFCDR (baseline) average			*0.118*
Lower locations			
SFCDR near Wallace	18.98	1998	0.045
SFCDR near Lake Gulch	17.78	1998	0.049
SFCDR near Lake Gulch	17.6	1996	0.003
SFCDR near Argentine Creek	16.58	1998	0.024
SFCDR near Twomile Creek	15.1	1998	0.003
SFCDR near Osburn	14.18	1998	0.010
SFCDR near Terror Gulch	13.3	1995	0.068
SFCDR near Terror Gulch	12.98	1998	0.009
SFCDR near Big Creek	11.78	1998	0.008
SFCDR near Big Creek	11.5	1994	0.009
SFCDR near Moon Creek	10.58	1998	0.004
SFCDR near Montgomery Creek	9.38	1998	0.015
SFCDR near Kellogg	8.8	1998	0.021
SFCDR near Pine Creek	2.8	1994	0.010
Lower SFCDR (injured) average			*0.020*

a. All density data included herein are derived from MPD electrofishing data.
Sources: R2 Resource Consultants (1995, 1996, 1997); Reiser et al. (1999); Stratus Consulting (1999).

Trout populations in mine-impacted streams

Downstream of mine impacts, there are no resident trout populations in either Canyon or Ninemile Creek (Stratus Consulting, 2000). There is a complete loss of surface water services in Ninemile Creek from at least the Interstate Mill downstream to the mouth, a distance of over 10.2 km (6.3 mi). Canyon Creek has no fish life downstream of Burke (Stratus Consulting, 2000), a distance of over 10.3 km (6.4 mi) (Table 4.1). While there are some resident trout in the SFCDR downstream of Canyon Creek, the average trout density is roughly six times lower than the average upstream trout density (Stratus Consulting, 2000) (Table 4.3).

Table 4.4 compares trout densities to baseline for each of the injured reaches. Canyon Creek and Ninemile Creek have the same trout density (0 trout/m^2). However, Canyon Creek covers more than twice as much area as Ninemile, so even though the baseline trout density is lower in Canyon Creek, the total loss of services is higher. The SFCDR has a resident trout population, but the average trout density is low compared to the upstream baseline trout density, and the injured river covers a large area as it flows some 20 miles from Canyon Creek to the North Fork confluence.

Table 4.4. Loss of trout services due to surface water injury

Reach	Area[a] (m^2) (acres)	Average density (fish/m^2)	Baseline density (fish/m^2)
Canyon Creek below Burke	82,268 (20.3)	0	0.055
Ninemile Creek below Interstate Mill	34,870 (8.6)	0	0.122
South Fork Coeur d'Alene below Canyon Creek	461,932 (114.1)	0.020[b]	0.118[c]

a. See Table 4.1 for length and width data.
b. N = 14, from 11 separate locations, on SFCDR downstream of Canyon Creek (Table 4.3).
c. N = 10, from 5 separate locations, on SFCDR upstream of Canyon Creek (Table 4.3).

Temporal loss

The service losses presented in the previous section account only for losses at a particular point in time. However, service losses accumulate for each year that the service is (or was) reduced or eliminated. To estimate future lost fishery services, improvements in trout populations that may occur as a result of EPA cleanup actions are accounted for.

According to the Record of Decision (U.S. EPA, 2002b), there are two projects that may lead to increased fish populations in the injured stream reaches described in Table 4.4. To determine how these projects might affect trout populations, we examined the relation between the magnitude of zinc ALC exceedences and fish density (Figure 4.1). We plotted paired surface water samples and trout density data from the SFCDR (Stratus Consulting, 1999) and from Pine Creek (McNary et al., 1995), as well the representative fish population (0) and 1998 average zinc ALC exceedence for Canyon Creek (Stratus Consulting, 2000). We then fitted a trend line to the data. This resulted in the following equation for determining fish density as a function of ALC exceedence:

$$D_{rb} = -33.508(\ln([Zn]/ALC_{Zn}) + 99.736,$$

where D_{rb} is fish density relative to baseline, and $[Zn]/ALC_{Zn}$ is the magnitude of zinc ALC exceedence. We did not include data from Ninemile Creek to generate this equation, because zinc concentrations in Ninemile were up to 100X ALC (Stratus Consulting, 2000), or 4 times greater than in Canyon Creek, with the same trout density as Canyon Creek (e.g., 0 trout/m^2). Thus, including the Ninemile Creek data would skew the curve, and accuracy at lower magnitudes of exceedence would be lost.

The ROD (U.S. EPA, 2002b) specifies projects for Ninemile Creek and SFCDR that would help restore trout populations over a 30-year time period. There are no instream remedies contemplated for Canyon Creek and, as a result, no interim benchmarks have been established. Therefore, it is assumed that Canyon Creek will continue to support no fish after 30 years. Ninemile Creek below Success is targeted to become a Tier 1 fishery. However, by definition, there are no resident trout in a Tier 1 fishery (U.S. EPA, 2002b). Therefore, there is no gain in trout populations in lower Ninemile Creek during the first 30 years after the signing of the ROD.

Table 4.5 shows two reaches within the mining-impacted areas that may show improved fish populations after 30 years. First is the 3-km stretch of East Fork Ninemile Creek above Success and below the Interstate Mill. This reach currently has no fish and has zinc concentrations in excess of 50X the ALC (EPA, 2002b). The ROD benchmark for this reach is 7X ALC, a Tier 3 fishery. Using the above equation to calculate the percent density relative to baseline (34.5%) and multiplying the result by the actual baseline density provides a predicted density of 0.042 trout/m^2 after 30 years (Table 4.5).

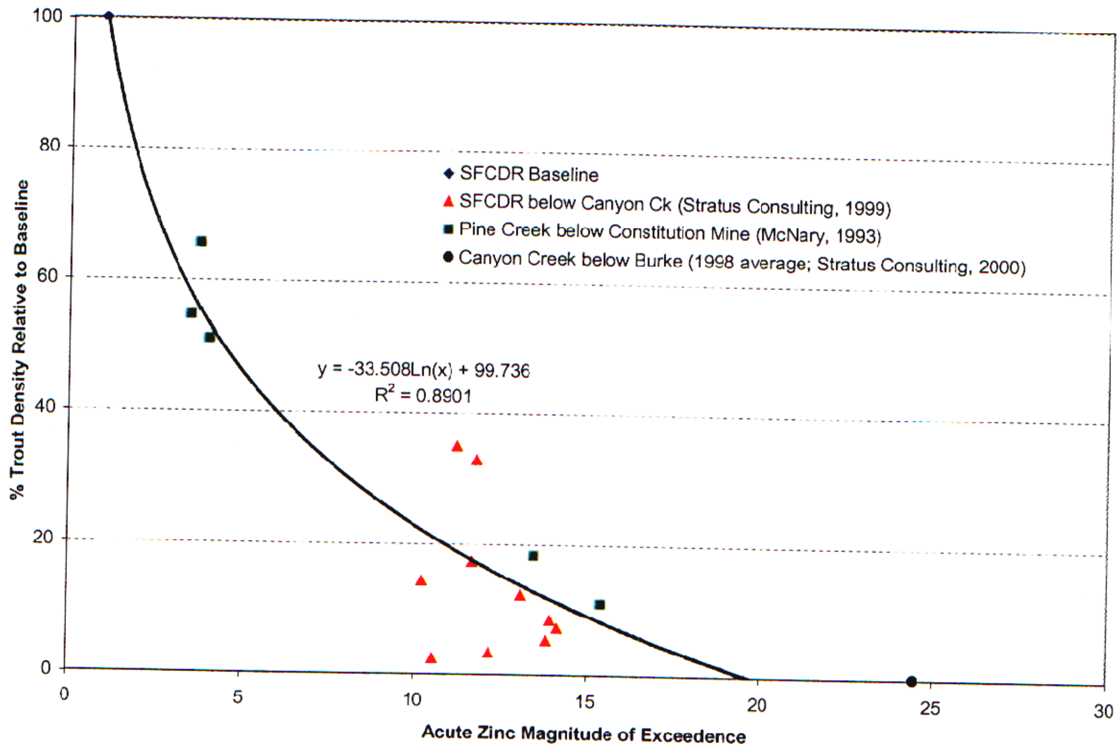


Figure 4.1. Fish density at mine-impacted sites relative to baseline, as a function of zinc ALC. The logarithmic trend line allows a prediction of future trout density based on the anticipated magnitude of ALC exceedence in the future.

Table 4.5. Recovery of trout services from EPA remedial actions[a]

Reach	Area[b] (m^2) (acres)	Initial avg. density (fish/m^2)	Predicted density after 30 years[c] (fish/m^2)
East Fork Ninemile Creek above Success and below Interstate Mill	9,521 (2.4)	0	0.042
South Fork Coeur d'Alene below Canyon Creek	461,932 (114.1)	0.020	0.041

a. Based on reaching predicted ALC benchmarks after 30 years, as described in the ROD (U.S. EPA, 2002b).
b. See Table 4.1 for length and width data.
c. The target benchmark is 7X ALC (Tier 3) for both Ninemile and SFCDR.

The ROD predicts a target zinc ALC exceedence magnitude of 7 for the SFCDR as well (EPA, 2002b). Typically, the zinc ALC in SFCDR ranges from about 7 to 15X ALC (URS Greiner and CH2M Hill, 2001a). Data sources compiled for the ROIA (Stratus Consulting, 2000) showed the average zinc ALC exceedence in the SFCDR data was over 15X. Based on the previous equation, we predict that fish density in the SFCDR would increase from 0.020 to 0.041 fish/m^2 after 30 years (Table 4.5).

4.2 Cost of Replacement

4.2.1 Approach

As discussed above, injuries to surface water resources of SFCDR, Ninemile Creek, and Canyon Creek have resulted in reduced ecological services, for which lost fish production can be used as an indicator. These losses extend into the past and will continue into the future. One approach to compensate for this service loss is to enhance aquatic habitat in other locations where metals do not limit services provided by surface water. Habitat enhancements in these other locations thus can provide replacement services that, like the surface water injuries, could be measured in terms of fish production (Strange et al., 2004). Habitat enhancement that will produce wild fish (and other surface water services), rather than simply adding fish through hatchery supplementation, is necessary to replace lost services. Fisheries biologists widely recognize that hatchery fish are not ecologically equivalent to wild fish because they often have reduced survivability, unnatural behavior, altered life history patterns, and altered genetic make-up that result in a reduced ability to provide ecological services (Meffe, 1992; McLean et al., 2003). Moreover, simply stocking hatchery fish would not replace lost ecological services.

We focused our analysis on projects that would replace the lost ecological services of surface waters provided by trout, specifically five species in the family Salmonidae that are found in streams in various portions of the Coeur d'Alene basin: westslope cutthroat trout (*Oncorhynchus clarki lewisi*); bull trout (*Salvelinus confluentus*); rainbow trout (*Oncorhynchus mykiss*); brown trout (*Salmo trutta*); and brook trout (*Salvelinus fontinalis*). However, it should be recognized that populations of other fish species such as sculpin (*Cottus* spp.) and mountain whitefish (*Prosopium williamsoni*) as well as benthic invertebrates have been injured by elevated metal concentrations in the SFCDR, Ninemile Creek, and Canyon Creek (Stratus Consulting, 2000; Maret and MacCoy, 2002). Our rationale for limiting the analysis to trout as an index of surface water services is that actions that enhance productivity of trout will also benefit the other aquatic biota. As a result, the remainder of the section focuses on the use of trout production as a quantitative index for surface water habitat enhancement.

4.2.2 Stressors other than metals that limit production of wild trout in injured areas of the Coeur d'Alene basin

Wild trout populations occur throughout much of the uninjured areas of the Coeur d'Alene basin, with cutthroat trout and brook trout being the most prevalent species (Horton and Mahan, 1988; Lillengreen et al., 1993; Hunt and Bjornn, 1995; Abbott, 2000). However, in these uninjured areas, habitat degradation from stressors other than metal contamination has reduced some trout populations. For example, streams on the Coeur d'Alene Tribe reservation with good habitat conditions can have trout densities as high as about 25 fish per 100 m^2, but streams with degraded habitat conditions can have trout densities below 1 fish per 100 m^2 (Coeur d'Alene Tribe Fisheries Program, unpublished data). Likewise, streams in the Panhandle National Forest can have trout densities as high as about 30 fish per m^2 if habitat conditions are good, but less than 5 fish per 100 m^2 when habitat conditions are poor (Abbott, 2000). Streams with good habitat conditions and abundant trout populations provide a benchmark for how much trout production in degraded habitats might be increased through habitat improvements.

We used three approaches to determine the types of stressors (other than metals) that are degrading habitat conditions and as such would provide opportunities for replacement projects. First, we reviewed previous studies done in the areas of the watershed not impacted by metals that discussed habitat conditions in relation to trout abundance. Second, we discussed the factors limiting fish production with local fisheries experts from the Panhandle National Forest and the Coeur d'Alene Tribe. Third, we conducted a site visit in July 2004 to the Panhandle National Forest and Coeur d'Alene Tribe reservation to view stream habitat conditions. Based on these sources of information, we identified four types of stressors that are degrading stream habitat and reducing trout production in portions of the Coeur d'Alene River basin where metals are not a problem. These stressors are channel alteration, loss of canopy cover and woody debris, sediment input, and habitat fragmentation (Table 4.6). The negative effects of these stressors on trout populations are well known to fisheries biologists and are summarized below.

Channel alterations

Channel alterations refer to changes in the stream course and stream bed that reduce channel complexity and eliminate fish habitat (Wesche, 1985; Orth and White, 1999). Stream channels have been straightened or even relocated to increase agricultural acreage in riparian meadows and to facilitate construction of roads and railways along valley bottoms. Channel straightening can eliminate meander bends, side channels, and riparian wetlands, and can reduce fish habitat. Meander bends are sites where scouring creates deep pools and where large woody debris accumulates, both of which are important components of fish habitat. As stream length is reduced in a reach through channelization, water velocity increases, especially during high flow events. The loss of slower water along the stream edge and in side channels can reduce rearing

Table 4.6. Four types of stressors (other than metals) that cause degraded fish habitat in streams of the Coeur d'Alene, St. Joe, and St. Maries river basins

Stressor type	Effects on fish habitat	Sources of information for Coeur d'Alene basin
Channel alteration	Loss of channel area reduces living space. Reduced habitat complexity due to loss of pools, undercut banks, or side channels eliminates habitat for various life history stages of trout.	Horton and Mahan (1988); Lillengreen et al. (1993); Vitale et al. (2002, 2003) Discussions with local biologists Site visit in July 2004
Loss of canopy and woody debris	Loss of large trees in riparian zone reduces inputs of large woody debris that provides overhead cover and create pool habitat for trout. Loss of shading by trees results in water temperatures too warm for trout.	Lillengreen et al. (1993) Abbott (2000); Vitale et al. (2002, 2003) Idaho DEQ (2001, 2003a, 2003b) Discussions with local biologists Site visit in July 2004
Sediment input	Fine sediments can smother trout eggs that are developing in nests in the gravel. Larger sediment particles can fill in pool habitat.	Lillengreen et al. (1993); Dunnigan et al. (1998); Vitale et al. (2002, 2003) Idaho DEQ (2001, 2003a, 2003b) Discussions with local biologists Site visit in July 2004
Habitat fragmentation	Culverts block upstream migration of fluvial and adfluvial trout to spawning areas. Roadways cut off side channels and backwater areas that are important as refuge habitat during floods or periods of high water temperatures in summer.	Lillengreen et al. (1993) Vitale et al. (2002, 2003) Discussions with local biologists Site visit in July 2004

habitat for young trout and eliminate refuges for all age classes during high flow events (Moore and Gregory, 1988). Also, faster water velocities can lead to downcutting; the channel can erode bottom substrates and become entrenched. Entrenched channels are less able to maintain a connection with their floodplain, and in some instances riparian vegetation can decline as the local water table drops. Entrenched channels also produce much sediment since the energy of flowing water cannot be dissipated onto the floodplain during high flow events.

In some of the larger streams in the Coeur d'Alene basin, channels have been altered by the removal of large woody debris jams. These woody debris jams were removed to facilitate use of rivers to float logs during early forestry operations and as a source of salvage logs for lumber. Large woody debris jams enhance channel complexity and create scour pools and cover utilized by trout. Without large woody debris jams, stream channels can be dominated by long expanses of shallow water that provide reduced habitat for trout.

Loss of canopy cover and woody debris

Timber harvest during the past century eliminated large trees in the riparian zone of many streams. As a result, there has been reduced recruitment of large trees into the stream channels. The importance of large woody debris in maintaining channel complexity, creating pools, and providing fish habitat is well known (Dolloff and Warren, 2003; Zalewski et al., 2003). Large trees that fall into streams create scour pools and dam pools, and root wads provide cover from predators. Trees help retain spawning gravels in high gradient channels and provide a substrate for invertebrates that are important as food for fish (Benke and Wallace, 2003).

Riparian trees also shade streams and have a strong influence on stream temperatures by maintaining cooler temperatures during the summer and warmer temperatures during the winter. The loss of riparian tree canopy can cause streams to be as much as 7°C (13°F) warmer in the summer than similar streams that are heavily shaded (Beschta and Taylor, 1988; Johnson and Jones, 2000). Stream warming due to the loss of riparian tree canopy is thought to be a limiting factor for trout populations for some streams on the Coeur d'Alene Tribe reservation, including Benewah, Lake, and Alder creeks (Vitale et al., 2002).

In addition to providing instream habitat and moderating stream temperatures, riparian vegetation also plays a major role in stabilizing stream banks, thus reducing sediment inputs to the stream (discussed below) and preventing channel widening. A common feature of streams with unstable banks is an increase in the width to depth ratio. This happens because high flow events cause bank erosion and thus widen the stream channel. However, when low flows return, the stream continues to span the widened channel and consequently is very shallow. Wide and shallow streams offer reduced cover for trout typically provided by undercut banks and overhanging riparian vegetation.

Sediment input

The detrimental effects of excessive sediment on habitat conditions and fish populations in streams are well known to fisheries biologists (Waters, 1995). Trout dig nests in the bottom substrate of streams and then cover the eggs with a layer of gravel. The embryos develop for weeks or months and require a flow of water through the nest to provide oxygen and remove metabolic wastes. An accumulation of fine sediments in the nest prevents water movement through the gravel and results in mortality of the developing embryos (Bjornn and Reiser, 1991). Coarse sediments also can be a problem because they can accumulate in pools, rendering the pools less suitable as trout habitat (Roni et al., 2002).

Sediment problems in the Coeur d'Alene basin often can result from roads or railways being located in the riparian zone. Studies have shown an increase in sediment delivery to streams with an increase in road density and the number of culvert crossings in a watershed (Furniss et al., 1991; Eaglin and Hubert, 1993). Roads or railway beds that form part of the stream bank are ready sources of sediments from erosion. Even roads and railways located away from the channel but within the floodplain contribute sediment to the channel during high flow events. Side ditches can intercept sediment-laden runoff from hillsides and direct it into the stream, especially where the road crosses a stream (Roni et al., 2002). Road culverts can be a problem because they can become plugged with debris and the stream subsequently erodes around the culvert, contributing much sediment to the stream channel (Furniss et al., 1991). Land-use activities that remove or disturb vegetation cover in a watershed lead to increased soil erosion and, subsequently, increased sediment input to streams. Logging and agricultural crop production can also result in increased sediment to streams (Chamberlin et al., 1991; Waters, 1995). Both of these are common land-use activities in various portions of the Coeur d'Alene River basin (USFS, 1998; ID DEQ, 2001, 2003a, 2003b). Dunnigan et al. (1998) indicated that bedload movement of sediments into pool habitat during high winter flows may be contributing to a reduced abundance of cutthroat trout in the Coeur d'Alene River basin.

Habitat fragmentation

Habitat fragmentation refers to the isolation of formerly connected habitats. Often the habitats are utilized at different times of the year or at different life stages; hence the ability to move among different habitats is important for many fish species (Schlosser, 1995; Schmetterling, 2001). When river drainages become fragmented, the ability of fish to utilize different habitat types is reduced (Rieman and Dunham, 2000). Transversing different habitat types throughout their life cycle is an important part of the biology of westslope cutthroat trout in the Coeur d'Alene River basin. Most spawning occurs in headwater or tributary streams, where juveniles then spend their first two to three years (Figure 4.2). At that point, trout may remain in headwater or tributary streams as adults (resident fish), move downstream to mainstem rivers (fluvial fish), or migrate to Coeur d'Alene Lake (adfluvial fish). Fluvial and adfluvial fish must then migrate back to headwater or tributary streams to reproduce, sometimes traveling 30-60 miles to reach suitable spawning areas (Lillengreen et al., 1993). Fluvial and resident fish also migrate between feeding areas in mainstem reaches and areas that provide refuge during high spring flows, hot summer temperatures, or severe winter conditions (Rieman and Apperson, 1989; Nielson et al., 1994; Brown and Mackay, 1995; Fredericks et al., 2002).

Because movement is an integral part of the biology of westslope cutthroat trout, factors that disrupt or prevent movements are detrimental to trout populations. In the Coeur d'Alene River basin, two factors have been identified that disrupt fish movements: road culverts and metal-contaminated water. Road culverts can block access to upstream spawning habitat if the structure is located too high above the stream for fish to jump into the culvert or if water velocities are too great for fish to swim through the culvert (Furniss et al., 1991). Barriers to migration can also be created by chemical conditions that cause fish to avoid stream reaches with elevated

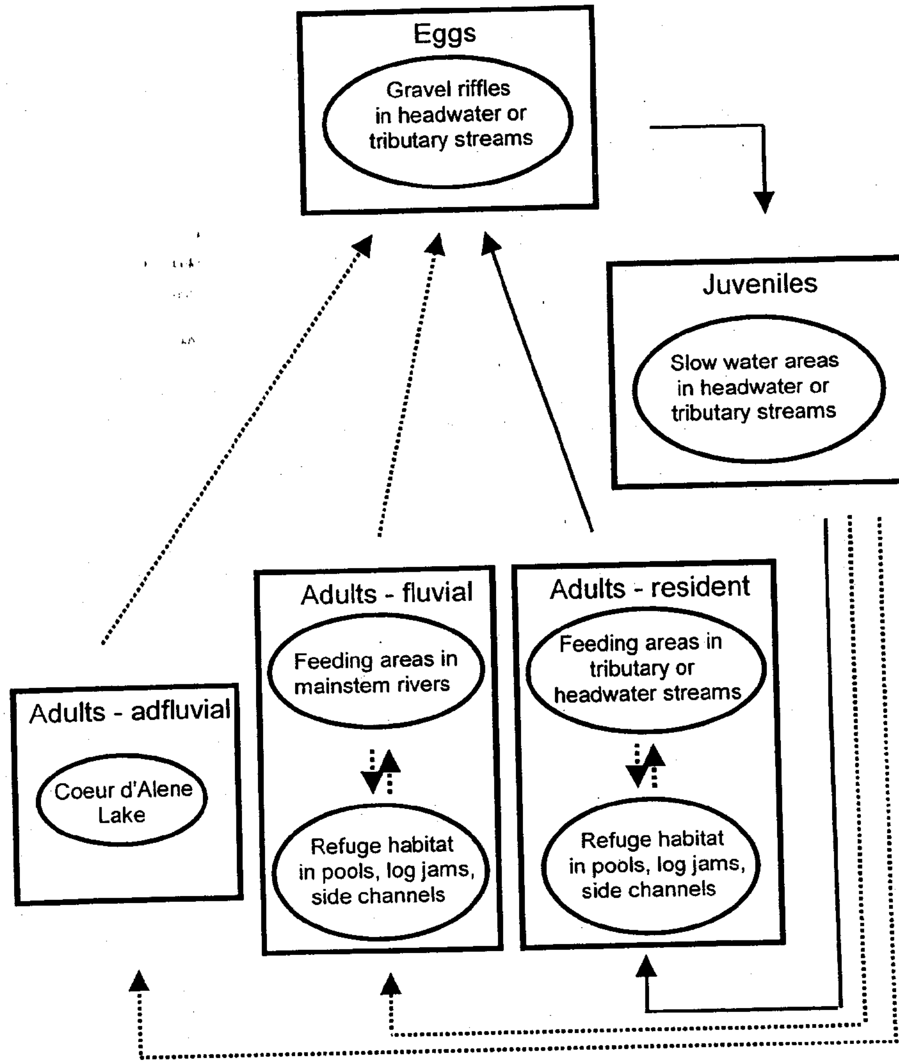


Figure 4.2. The life history stages of cutthroat trout in the Coeur d'Alene River basin. Spawning occurs in headwater or small tributary streams, where juveniles spend 2-3 years rearing. At that point, trout may remain in headwater or tributary streams as adults (resident fish), move downstream to mainstem rivers (fluvial fish), or migrate to Coeur d'Alene Lake (adfluvial fish). All three groups spawn in headwater or tributary streams. Fish movements (indicated by dashed lines) involve migration of juveniles to mainstem or lake habitat, seasonal movements of resident and fluvial fish between feeding and refuge areas, and migration of adfluvial and fluvial fish to spawning areas.

concentrations of metals. There is evidence that migrating fish in the Coeur d'Alene River avoid reaches with elevated metal concentrations and thus may not be able to utilize some spawning tributaries (Woodward et al., 1997).

Another aspect of habitat fragmentation is the loss of side channels and backwater areas due to stream channelization or the construction of highways (Figure 4.3) and railway beds (Figure 4.4) that block access to these areas (Roni et al., 2002). These off-channel areas can be important seasonal habitats that allow fish to survive harsh conditions due to floods, summer heat, or winter ice (Nielson et al., 1994; Solazzi et al., 2000).

Figure 4.3. Photograph of road bed forming part of the bank of a stream.

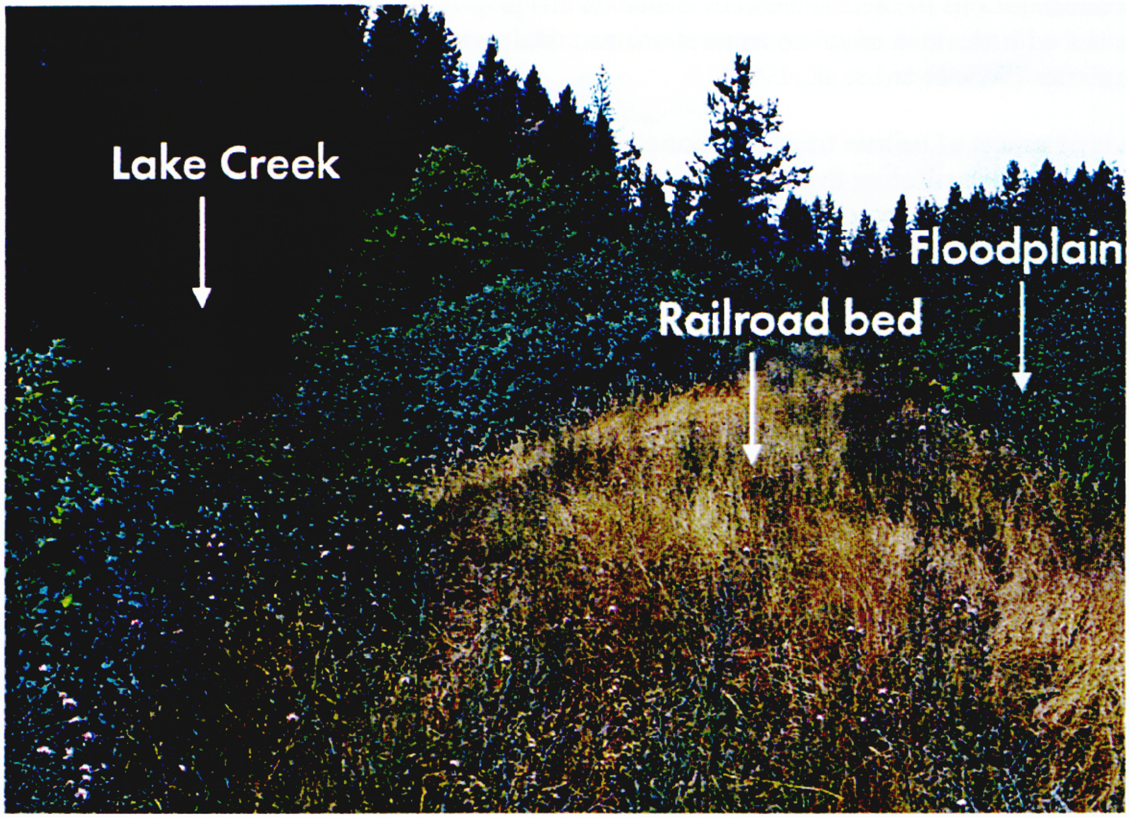


Figure 4.4. Abandoned railway bed along Lake Creek downstream of Highway 95 on the Coeur d'Alene Tribe reservation. The elevated railroad bed is contributing sediment to the stream and preventing the stream from interacting with its historical floodplain.

4.2.3 Project opportunities to enhance production of wild trout in the Coeur d'Alene basin

Biologists have long recognized the negative effects of channel alteration, loss of canopy and woody debris, sediment input, and habitat fragmentation on fish populations. There is a long history of stream habitat improvement projects dating back to the early 20th century (e.g., Tarzwell, 1932). During the past 50 years, a variety of approaches have become commonplace for improving degraded stream habitat (see reviews in Wesche, 1985; Orth and White, 1999; Roni et al., 2002). There are many examples of fish populations responding positively to stream habitat improvements. In 46 stream habitat improvement projects done in Wyoming from 1953 to 1998, wild trout abundance increased by an average of 116% (Binns, 1999). In 58 trout stream habitat improvement projects done in Wisconsin from 1985 to 2000, the average increase in trout biomass was 63% (Avery, 2004). Numerous examples of successful stream habitat improvement projects in the western United States are described in a restoration project database maintained by the Montana Water Center (2004).

After reviewing the literature on fish habitat improvement projects and after consultation with local fisheries biologists from the Coeur d'Alene Tribe and the U.S. Forest Service, we identified seven types of projects that potentially could be used to mitigate the negative effects of the four stressors on trout production in streams within the Coeur d'Alene River basin (Table 4.7). Each of these is discussed below and all appear generally feasible in the Coeur d'Alene River basin. In many cases, similar projects have already been undertaken in the basin and have resulted in improved habitat for trout.

Table 4.7. Four types of stressors that degrade habitat and reduce trout production in streams in the Coeur d'Alene, St. Joe, and St. Maries drainages and seven categories of enhancement projects that would mitigate the effects of each stressor

	Habitat enhancement project categories						
Stressor type	**Channel reconfiguration**	**Road/ railway bed relocation**	**Mainstem bank structures**	**Wood addition**	**Culvert improvement**	**Side channel restoration**	**Canopy restoration**
Channel alteration	X	X	X	X		X	
Loss of canopy and woody debris	X	X	X	X			X
Sediment input		X		X	X		
Habitat fragmentation					X	X	

We also considered the scope of opportunity for implementing the various types of projects in the Coeur d'Alene Lake basin. In general, the scope of opportunity was expressed as miles of streams that could be rehabilitated using a given project type to enhance fish production. Because the mix of stressors differs somewhat between streams managed by the Coeur d'Alene Tribe and the U.S. Forest Service, we discuss separately examples of project opportunities for the Coeur d'Alene Tribe reservation (Table 4.8) and the North Fork of the Coeur d'Alene River basin in the Panhandle National Forest (Table 4.9). Nevertheless, the overall approaches to habitat enhancement that could be done on the reservation and in the National Forest are generally similar.

Table 4.8. Scope of habitat enhancement project opportunities in relation to major stressors limiting fish production in streams on the Coeur d'Alene Tribe reservation. The extent of degraded habitat is expressed as miles of stream (for loss of canopy cover and woody debris inputs, and channel alteration) or acres of land (for sediment inputs and loss of wetland function). The total miles of degraded stream habitat may include reaches affected by both loss of canopy and woody debris inputs and channel alteration, and may include miles of stream encompassed by the acres of land contributing sediment inputs or having a loss of wetland function. Thus, remediation may involve addressing multiple stressors for some stream reaches. Data were provided by the Coeur d'Alene Tribe Fisheries Program.

Watershed	Total miles of degraded stream habitat	Miles of stream affected by loss of canopy and woody debris inputs	Miles of stream affected by channel alteration	Sediment inputs: Miles of road needing relocation	Sediment inputs: Acres contributing sediments	Loss of wetland function (acres that need to be rehabilitated or created)
Alder	2.06	1.64	1.23	1.6	70	72
Benewah	10.78	3.76	2.88	13.6	943	588
Evans	3.59	0	2.35	1.8	235	31
Lake	8.12	3.28	5.01	4.0	704	317
Totals	24.55	8.68	11.47	21.0	1,952	1,008

Table 4.9. Habitat enhancement project opportunities that would alleviate stressors causing habitat degradation in streams in the Panhandle National Forest. The project types are presented in relation to stream size categories because some projects may be feasible only in streams within a certain size range. Also, project costs may vary with the size of the stream.

Project type	Project opportunities in relation to stream size: Small streams	Medium streams	Large streams
Channel configuration		X	
Road/railway bed relocation	X	X	
Mainstem bank structures			X
Wood addition	X	X	X
Culvert improvement	X		
Side channel restoration			X

Channel reconfiguration

Channel reconfiguration refers to returning the stream to its original channel where possible, recreating natural meander patterns, reversing downcutting, and restoring the stream's connection with its floodplain. It may involve the removal of levees that constrain the channel and prevent the stream from entering the floodplain and side channel areas during high flood events. It may involve the installation of instream grade control structures to raise the water level and restore areas with severe downcutting of the stream channel. It may involve addition of rocks and wood structures to redirect streamflow in order to scour pools and prevent bank erosion. The main stressors addressed through channel reconfiguration would be restoring channels that have been altered from their historical form and restoration of canopy cover and woody debris (Table 4.7). The Fisheries Program of the Coeur d'Alene Tribe has identified some 11 miles of streams in four watersheds that have been affected by channel alterations and are in need of channel and stream bank reconstruction (Table 4.8).

An example of a project on the Panhandle National Forest that involved extensive channel reconfiguration is Tepee Creek, a tributary of the North Fork of the Coeur d'Alene River (Figure 4.5). The original stream channel had been relocated to one side of a broad valley to facilitate hay production. From 1999 through 2000, a 1.1 mile long section of Tepee Creek was moved back to its original channel and numerous structures were placed in the stream to re-create meanders, prevent bank erosion and stream downcutting, and scour pool habitat for trout (project summary provided by the Coeur d'Alene River Ranger District, Idaho Panhandle National Forest, July 2004). These structures included rootwad revetments, rock and log barbs, j-hook vanes, and woodpiles placed in the floodplain. Angler reports indicate an improvement in the abundance of trout in the reconstructed portion of Tepee Creek.

Road and railway bed relocation

Roads or railways that were built adjacent to a stream prevent the stream from interacting with its floodplain and can be major sources of sediment. Often riparian roads become flooded during high flow events and thus are not available for use by the public. Many riparian roads and some abandoned railway beds exist within the Coeur d'Alene, St. Joe, and St. Maries River basins where the mountainous topography made building roads in stream floodplains the easiest option. Relocating roads to higher elevations and removing abandoned railway beds would help reduce the negative effects associated with three stressors: channel alteration, loss of canopy cover and woody debris, and sediment input (Table 4.7). Dunnigan et al. (1998) found that the frequency of pools in streams in the North Fork of the Coeur d'Alene River was negatively related to watershed road density. They also suggested that sediments derived from roads can fill in pool habitats during high winter flows and may be a factor contributing to reduced cutthroat trout

Figure 4.5. Photograph of a channel reconstruction project on Tepee Creek in the Panhandle National Forest. A 1.1 mile reach was restored by moving the stream away from a channelized streambed that had been dug along one side of the valley and restoring the natural meander pattern seen above. Rocks and logs were placed in the stream to create scour pools and protect the bank from erosion.

abundance. The Fisheries Program of the Coeur d'Alene Tribe has indicated that approximately 1,000 acres of land and 20 miles of road in four watersheds need to be rehabilitated to reduce sediment inputs (Table 4.8).

During our site visit to the Coeur d'Alene River basin in July 2004, we saw a road along Yellow Dog Creek (a tributary of the North Fork of the Coeur d'Alene River) that has been identified by the Idaho DEQ (2001) as a source of sediment inputs to the North Fork of the Coeur d'Alene River (Figure 4.3). We also saw a road in the floodplain of Burnt Cabin Creek that is subject to being washed out during highflow events and which is contributing sediment to the stream. On the Coeur d'Alene Tribe reservation, we saw an abandoned railway bed on Lake Creek that is eroding sediment into the stream and preventing the stream from overflowing into its historical floodplain (Figure 4.4). These are examples of opportunities for replacement projects.

Mainstem bank structures

In larger rivers such as the North Fork of the Coeur d'Alene River downstream of the confluence with Tepee Creek, it can be difficult or impossible to maintain instream structures that span the entire channel because they get blown out during high flow events. However, structures such as rock barbs (Figure 4.6) that are anchored into the stream bank have proven successful in increasing trout abundance. These structures deflect current away from shore and thus create deep pools off the end of the structure. Interstitial spaces among the rocks also provide cover for trout. Mainstem bank structures help alleviate the negative effects of two types of stressors: channel alteration (e.g., where natural meander and side channel pools have been lost) and loss of canopy cover and woody debris (especially large trees that historically formed large debris jams along mainstem river channels).

Figure 4.6. Photograph of rock barbs in North Fork of the Coeur d'Alene River above confluence with Big Hank Creek. These barbs are pointed upstream and direct current away the bank and result in the formation of a scour pool off the end of the barb.

We saw rock barbs in the North Fork of the Coeur d'Alene River near the Big Hank campground during our field trip in July 2004 (Figure 4.6). Conversations with Forest Service biologists indicated that the abundance of large cutthroat trout had increased in the pools created by these bank structures. Trout habitat could be improved through the addition of bank structures in other reaches of the North Fork of the Coeur d'Alene River that are currently too wide and shallow riffle to support high trout densities. Although the bank structures we saw were made out of rock, large trees cabled together and anchored into the bank would serve a similar purpose.

Wood addition

Wood serves a variety of functions in streams, including slowing the flow of water through a channel (and thus reducing its erosive force), creating pools, protecting banks from erosion, providing cover from predators, and serving as a refuge for fish during high flow events (Dolloff and Warren, 2003; Zalewski et al., 2003). Addition of wood to streams would help alleviate three stressors on trout populations: channel alteration, loss of canopy cover and woody debris, and sediment input (Table 4.7). In general, large pieces of wood are more effective than small pieces in providing fish habitat because large pieces are less likely to be displaced downstream or moved out of the channel during high flow events. However, past logging and road building have greatly reduced the number of large trees growing along streams in the Coeur d'Alene River basin (Vitale et al., 2002).

Natural inputs of large woody debris occur as big trees die and fall into the stream channel. To foster natural inputs, logging has been curtailed in the riparian zone in many watersheds in the Coeur d'Alene River basin. For example, no removal of large, overstory trees is permitted within 100 feet of either side of perennial streams on Coeur d'Alene Tribe lands (Booth, 2002). Similar restrictions on harvest of trees in the riparian zone exist for lands managed by the U.S. Forest Service (USFS, 1995). However, it can take 70-100 years for the growth of large conifer trees (Roni et al., 2002). In the meantime, there are many opportunities to improve trout habitat by adding large woody debris to streams in the Coeur d'Alene River basin.

During our site visit in July 2004, we observed several instances where addition of wood had been used to enhance fish habitat in streams. For example, in the North Fork of the Coeur d'Alene River drainage, placement of logs across Hudlow Creek resulted in the creation of plunge pools, which are important habitat for trout (Figure 4.7). Similar pools created by logs placed across the stream channel were observed in Big Hank Creek. In Benewah Creek on the Coeur d'Alene Tribe reservation, we observed large woody debris that had recently been added to side channels to provide refuge habitat for fish when the channels are filled with water during high flows (Figure 4.8).

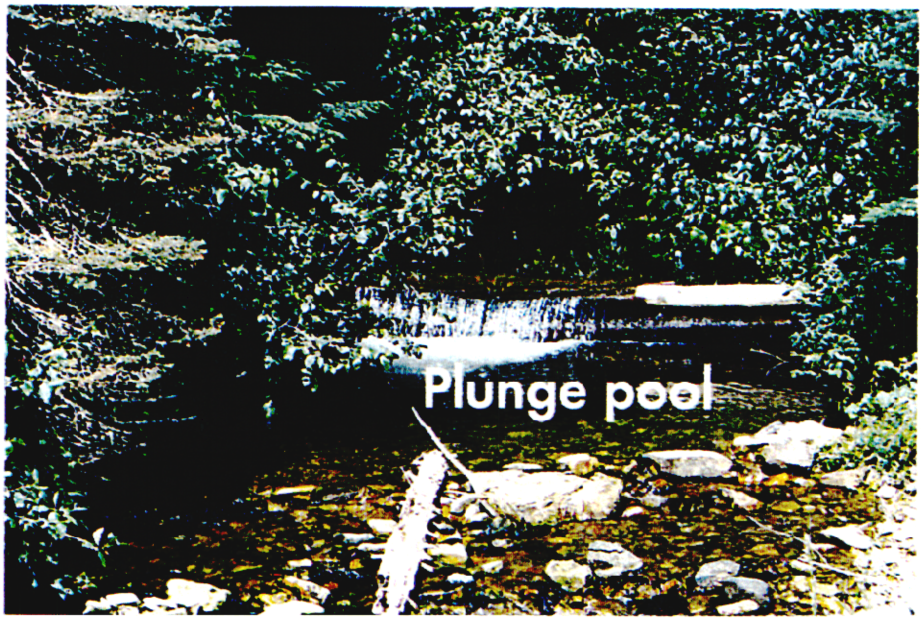


Figure 4.7. Addition of logs across Hudlow Creek resulted in creation of a plunge pool that serves as trout habitat.

Figure 4.8. Large woody debris placed into a side channel of Benewah Creek. During high flow periods, the side channel contains water and the woody debris provides cover for trout.

Culvert improvement

Culverts are associated with two types of stressors on trout populations in the Coeur d'Alene River basin: sediment input and habitat fragmentation (Table 4.7). Sediment inputs occur when culverts get dammed by debris accumulation during high flow events, causing the stream to erode around the culvert. Culverts also can be barriers to upstream movement of fish to spawning areas in tributary streams. In such cases, culverts cause fragmentation of stream networks. Numerous road culverts exist throughout the Coeur d'Alene River, St. Joe River, and St. Maries River basins. Roni et al. (2002) indicated that creating access to currently inaccessible tributary streams with good habitat is one of the most effective and cost-efficient methods for enhancing fish populations in a drainage. However, as discussed below, realistic quantification of the benefits of such projects is problematic.

During our field trip in July 2004, we observed a culvert on Windfall Creek that was preventing adfluvial cutthroat from Coeur d'Alene Lake from reaching spawning habitat in Windfall Creek (Figure 4.9). To correct this problem, a larger culvert that has no water drop at the downstream end could be installed. An even better alternative is using an arch culvert or prefabricated concrete deck crossing set on cement footings. We observed an arch culvert on cement footings on Hudlow Creek in the North Fork of the Coeur d'Alene River drainage (Figure 4.10). Such a culvert allows the natural stream channel to be retained and would be large enough that virtually all debris carried during high flow events could pass through the culvert without damming it.

Figure 4.9. A road culvert on Windfall Creek near its confluence with Benewah Creek on the Coeur d'Alene Tribe reservation. This culvert blocks upstream passage of fish and prevents adfluvial trout from Coeur d'Alene Lake from spawning in Windfall Creek.

Figure 4.10. A road culvert on Hudlow Creek that consists of a corrugated arch set on cement footings. The natural stream bed is retained and there is no water drop at the downstream end to block upstream movement of trout. The structure is large enough to allow debris to pass through without damming the culvert during high flows.

Side channel restoration

When building highways along mainstem rivers, it often was most expedient to put the road bed across large meander bends and side channels. Although this resulted in a straighter road, it severed these off-channel habitats from the main river channel and made them inaccessible to fish. Trout use these habitats seasonally as refuges from winter and spring floods. In some cases, these off-channel habitats receive substantial groundwater input and thus provide a cool-water refuge during periods of high water temperatures. Utilization of off-channel habitats along the North Fork of the Coeur d'Alene River during periods of high water temperatures in the mainstem has been observed by area fisheries biologists. As with culverts, however, realistic quantification of the benefits of such projects is problematic, as discussed below.

During a site visit to the Coeur d'Alene River basin in July 2004, we observed areas where highway construction had isolated side channel and backwater areas that would have historically been connected to the North Fork of the Coeur d'Alene River. Reconnecting these off-channel habitats can be done by allowing water to flow under the road, either through building bridges over the side channels or by placing oversized culverts through the road bed. Such modifications would address two stressors having a negative effect on trout populations: channel alteration and habitat fragmentation (Table 4.7).

Canopy restoration

Restoring the riparian canopy would alleviate the negative effects on trout populations associated with the "loss of canopy cover and woody debris" stressor (Table 4.8). As mentioned previously, restoring riparian trees would allow for the eventual recruitment of large wood debris into stream channels. Such benefits will not be realized for 70 to 100 years, since it takes that long to grow the large conifer trees that historically provided large woody debris to streams in the region. However, restoring riparian vegetation provides another benefit that can realized over a shorter time frame: canopy closure that shades the stream and reduces summer water temperatures. Warm summer temperatures are especially a concern for the larger streams on the Coeur d'Alene Tribe reservation (Lillengreen et al., 1993; Vitale et al., 2002). A total of 8.68 miles of tribal streams have been identified for canopy rehabilitation through the planting of riparian trees (Table 4.8).

Restoring riparian trees can be done passively, by not allowing future logging in the riparian zone. However, planting trees would hasten the closure of the canopy over the stream. During our July 2004 field trip, we observed newly planted conifer trees along Bozard Creek (Lake Creek drainage) on the Coeur d'Alene Tribe reservation, in a pasture where hay had been harvested right up to the stream's edge. Another situation where planting riparian trees would accelerate canopy closure and alleviate warm summer water temperatures is on the main stem of Benewah Creek on the Coeur d'Alene Tribe reservation. Because of a history of livestock grazing and hay production, few trees occur along some stretches of this creek, which is now being managed for trout habitat by the Coeur d'Alene Tribe (Figure 4.11).

4.2.4 Project benefits

To calculate the expected benefits from the projects outlined in Tables 4.8 and 4.9, we needed to estimate the increase in trout production that would result from an improvement in stream habitat. To do this, we assumed that trout densities in a degraded habitat could eventually approach densities that currently exist in relatively unimpacted habitat in the same area. To assess potential changes in trout abundance that could be associated with habitat enhancements, we examined data on fish abundance in streams managed by the Coeur d'Alene Tribe and by the U.S. Forest Service.

Figure 4.11. A section of the main stem of Benewah Creek that has few trees to shade the stream. Trees were prevented from growing by hay production and livestock grazing. This section of Benewah Creek is considered too warm to support cutthroat trout in the summer and would benefit from development of a tree canopy to shade the stream.

The Coeur d'Alene Tribe Fisheries Program has fish population data for 47 sites that spanned a range from relatively pristine to degraded habitats. Trout population sizes had been estimated annually from 1996 to 2003 by depletion-electrofishing and we calculated the average trout abundance at each site over this eight-year period. Where brook trout and westslope cutthroat trout were present in the same reach, we combined their numbers because we were interested in determining the maximum abundance of all trout that could be supported in various streams on the reservation. We also stratified the streams into two size categories, small (1st and 2nd order streams) and medium (3rd and 4th order streams), because rehabilitation/enhancement project opportunities and fish densities differed somewhat between these two size categories. Of the 47 sites on tribal land, 20 were small streams and 27 were medium streams.

For each stream size, we used the 20th percentile of trout density as an estimate of current trout densities in stream sites with poor habitat. We assumed that with habitat improvements, trout densities at these sites would increase to values currently found at sites with good habitat. We used the 80th percentile of site densities as an estimate of the trout density at sites with good habitat.

For the 20 small streams, the density of trout ranged from a high of 29.1 per 100 m^2 in the West Fork of Benewah Creek to a low of 5.5 per 100 m^2 in a site on Lake Creek (Figure 4.12). The 20th percentile of trout density was about 10 fish per 100 m^2. The 80th percentile of trout densities was 20 trout per 100 m^2. Thus, we estimated that implementation of habitat improvement projects on small streams on the Coeur d'Alene Tribe reservation would result in an increase in trout abundance from 10 to 20 fish per 100 m^2, or 10 trout per 100 m^2 (Table 4.10).

For the 27 medium streams, the density of trout ranged from a high of 12.0 per 100 m^2 at a site on Evans Creek to a low of 0.3 per 100 m^2 at a site on Alder Creek (Figure 4.13). The 20th percentile of trout density was about 0.6 fish per 100 m^2. The 80th percentile of trout density was about 6 fish per 100 m^2. However, none of the medium streams is considered to have good trout habitat at present and therefore 6 fish per 100 m^2 may underestimate the potential densities these streams might be able to reach following habitat improvement. In the absence of other information for medium streams on the Coeur d'Alene reservation, we used the value obtained from small streams with good habitat (20 trout per 100 m^2) as an estimate of densities that could be achieved in medium streams following habitat improvement (Table 4.10). This yields an estimated increase in trout abundance of 19.4 trout per 100 m^2.

To assess the range of trout abundance in streams managed by the U.S. Forest Service, we used data collected by Dunnigan (1997) and Abbott (2000). Westslope cutthroat trout population sizes had been estimated in 55 reaches in the North Fork of the Coeur d'Alene River in 1995 either by depletion-electrofishing or by single-pass electrofishing estimates adjusted for capture efficiency. The average abundance of trout ranged from a high of 39.5 per 100 m^2 in Lost Fork Creek to a low of 1.9 per 100 m^2 in Coal Creek (Figure 4.14). The 20th percentile of trout density was about 4 fish per 100 m^2. The 80th percentile of trout density was 15 trout per 100 m^2. Thus, we estimated that implementation of habitat improvement projects on streams in the North Fork of the Coeur d'Alene River basin would result in an increase in trout abundance from 4 to 15 fish per 100 m^2, or 11 trout per 100 m^2.

For purposes of modeling the response of trout to various project types in the overall region, we averaged the three values presented above to derive a regional estimate of anticipated enhancement project benefits. The average of these three values (10, 19.4, and 11) was an anticipated net improvement of 13.5 trout per 100 m^2.

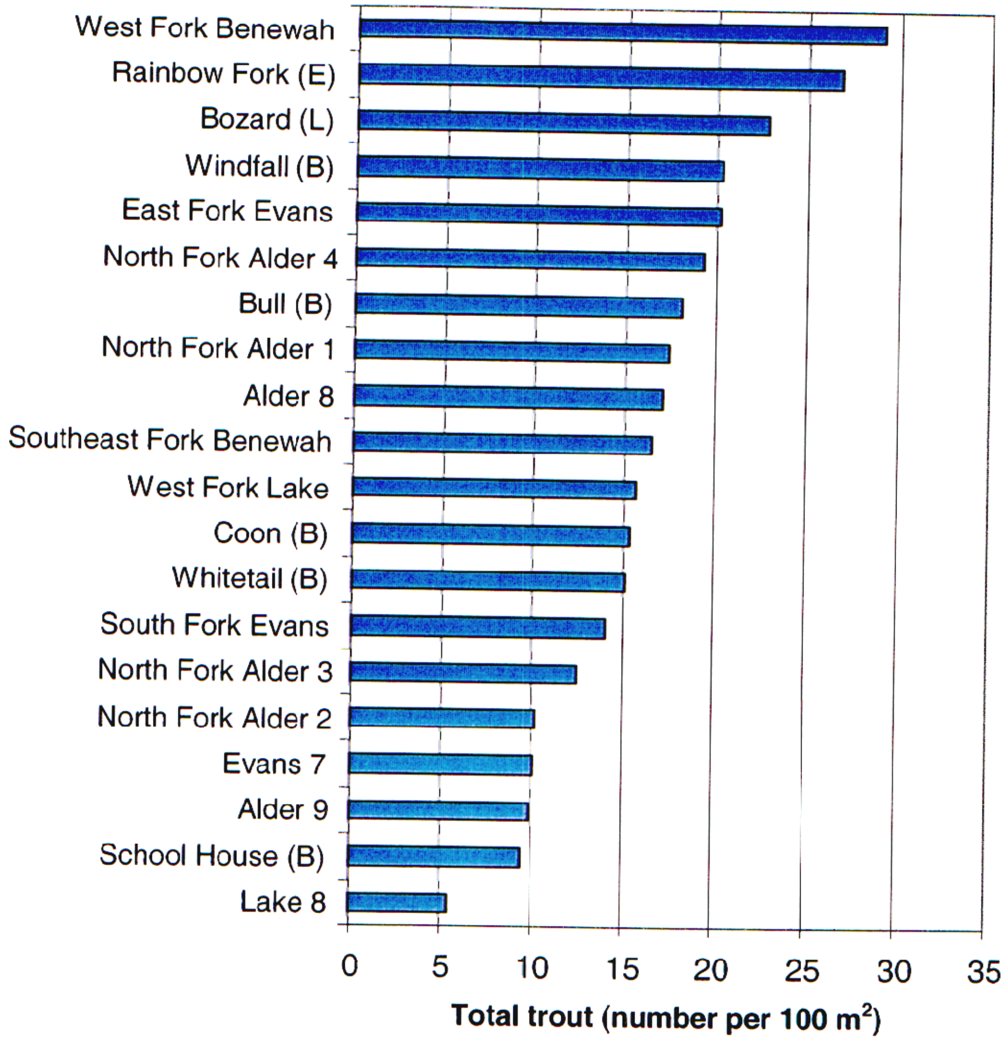


Figure 4.12. Trout abundance at 20 small (1st and 2nd order) stream sites on the Coeur d'Alene Tribe reservation. Sites were in four drainages: Alder Creek (A); Benewah Creek (B); Evans Creek (E); Lake Creek (L).

Table 4.10. Remediation/improvement project opportunities for streams on the Coeur d'Alene Tribe reservation. The total miles of stream needing rehabilitation/improvement are indicated for four watersheds. Streams were partitioned into small (1st-2nd order) and medium (3rd-4th order) categories. Current fish densities in degraded reaches and predicted fish densities after project implementation are shown for both stream size categories.

Watershed	Total stream miles needing rehabilitation	Miles of 1st-2nd order streams needing rehabilitation	Current fish density for degraded 1st-2nd order streams (#fish/100 m^2)	Target fish density for rehabilitated 1st-2nd order streams (#fish/100 m^2)	Miles of 3rd-4th order streams needing rehabilitation	Current fish density for degraded 3rd-4th order streams (#fish/100 m^2)	Target fish density for rehabilitated 3rd-4th order streams (#fish/100 m^2)
Alder	2.06	0.19	10	20	1.87	0.6	20
Benewah	10.78	7.16	10	20	3.62	0.6	20
Evans	3.59	1.17	10	20	2.42	0.6	20
Lake	8.12	4.57	10	20	3.56	0.6	20
Total	24.55	13.09			11.47		

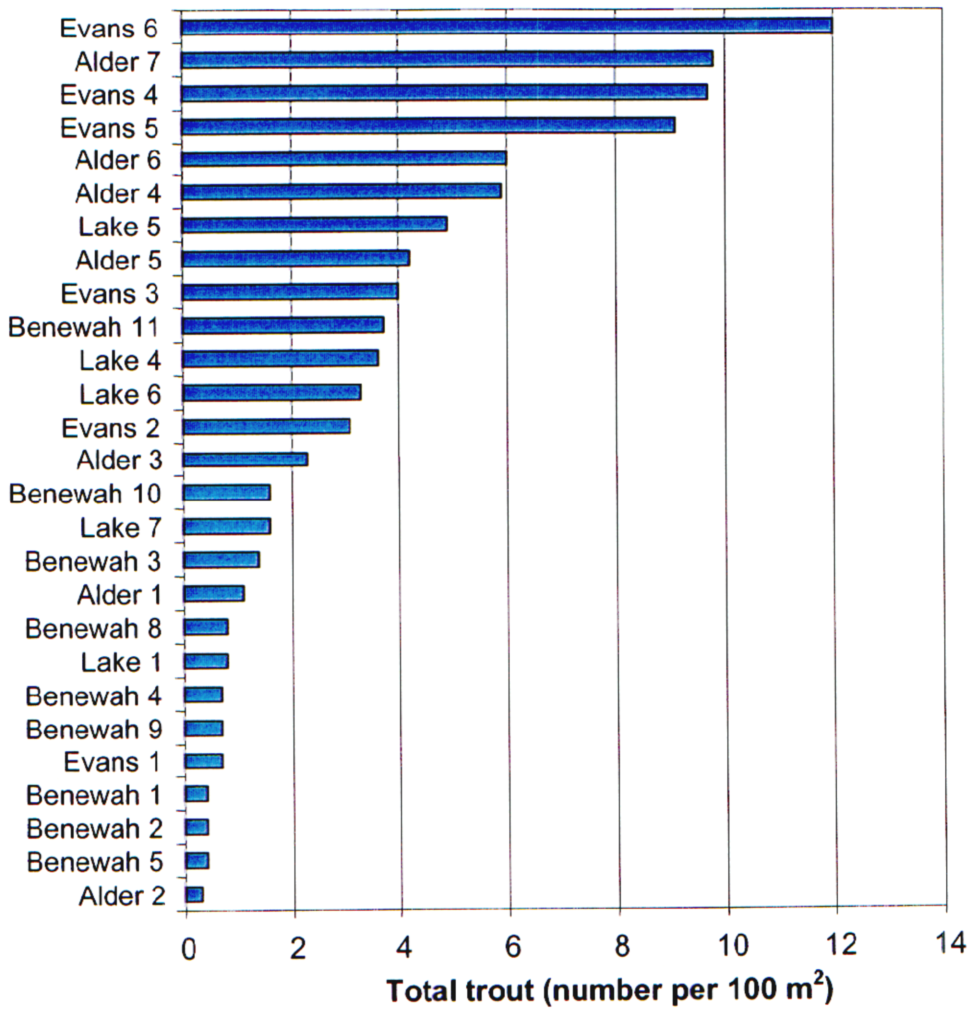


Figure 4.13. Trout abundance at 27 medium (3rd and 4th order) stream sites on the Coeur d'Alene Tribe reservation. Sites were in four drainages: Alder Creek; Benewah Creek; Evans Creek; Lake Creek.

We also estimated the time period required for trout populations to respond to habitat improvements. Wesche (1985) noted that trout populations may not respond to habitat improvements instantly and suggested that "it may be best to wait at least four years" before assessing the impact of projects on trout populations. There is evidence that trout populations may require more than a single generation to achieve the maximum response to habitat improvements. Hunt (1976) examined the response of brook trout to channel reconfiguration

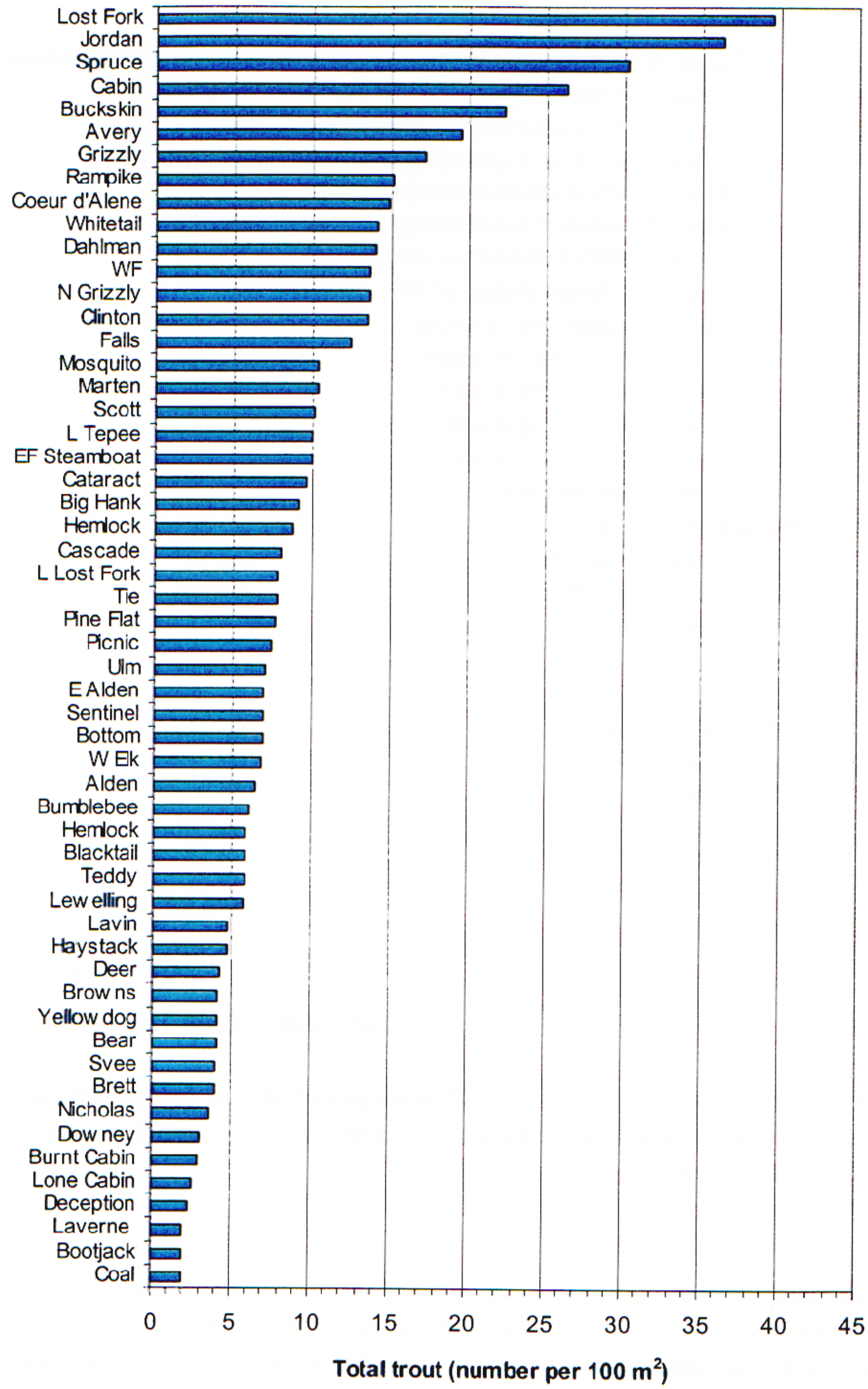


Figure 4.14. Trout abundance in streams in the North Fork of the Coeur d'Alene River drainage in 1995 (data from Abbott, 2000).

projects in a Wisconsin stream and concluded that the population was continuing to show improvement six years later, when his study ended. Binns (1994) noted that the biomass of brook trout peaked seven years after habitat improvements were made on a Wyoming stream. Brook trout have a generation time of two-three years, hence the improvements noted by Hunt (1976) and Binns (1994) took place over two-three generations. Fisheries biologists for the Coeur d'Alene Tribe have estimated that it would take several generations for adfluvial cutthroat trout populations to respond fully to channel reconfiguration improvements (Vitale et al., 2002). We used two generations as the time period required to achieve maximum increases in trout production following habitat rehabilitation and improvement projects.

Projects on the Coeur d'Alene Tribe reservation are focused on increasing the abundance of adfluvial cutthroat trout, which become sexually mature between the ages of 5-6 (Vitale et al., 2003). Hence, two generations would require between 10 and 12 years. Most westslope cutthroat trout in the Coeur d'Alene River system reach sexual maturity between ages 4 and 6 (Rieman and Apperson, 1989), which means that two generations would require 8-12 years. We used 10 years as the time period required for projects to achieve the full benefit in terms of increased trout production. Over this time period, we assumed a linear increase in trout densities from starting values to ending values.

The only exception to this recovery period would be for projects that involve restoration of riparian canopies and woody debris inputs through planting of coniferous trees. Conifer trees require 50-100 years or more to reach a size where they would completely shade the stream and be able to supply large woody debris to the channel (Roni et al., 2002).

Finally, we estimated the spatial area over which benefits would be expected to occur. For three of the project types, road/railway relocation, mainstem bank structures, and wood addition, we estimated that increases in trout production occur over the stream reach that is treated (i.e., project implementation along 1 mile of stream would result in increased trout production in that mile). The channel configuration project type involves both habitat improvements and increases in the total amount of habitat (because configuration results in increasing the amount of stream meanders, thus lengthening the stream). We estimated that, on average, such projects would result in a 100% increase in the total amount of stream habitat (i.e., 1 mile of stream treatment would generate increased trout production over 2 miles). To calculate the benefits of such projects, we assumed an initial density of 4 trout per 100 m^2 in the treated stream segment (from the National Forest data cited previously). Total project benefits thus would equal 13.5 trout per 100 m^2 + 17.5 trout per 100 m^2 (the assumed starting density plus the added 13.5 trout) to account for the additional area of habitat created. Thus, total project benefits for the channel reconfiguration project are estimated to be 31 trout per 100 m^2 of injured habitat.

For culvert management projects, benefits might occur upstream and/or downstream of improvement location, as well as in lakes where adfluvial trout reside for part of their life. This means that estimating the improvements on an areal basis would be problematic because there is no clear basis for calculating the specific area over which benefits should be calculated. In addition, the degree of benefit may be highly variable because of interactions with resident populations up and downstream of the project locations. For these reasons, this project type was not used in the damage calculations.

There is a similar problem in determining the area that would receive benefits for projects involving side channel connection. The benefits of side channel connection could be realized not only within the side channel itself but also in the main stem of the river upstream and downstream of the project location. This is because side channels can benefit trout in the mainstem river by providing a seasonal refuge from high flows, harsh winter conditions, and hot summer temperatures. However, the length of river and the duration (e.g., season, water level) over which these benefits would be realized are not known. Therefore, it is problematic to calculate a realistic value for the areal extent of benefits to use in damage calculations. For this reason, this project type also was not used in the damage calculations.

4.2.5 Project feasibility

As discussed previously, opportunities for aquatic habitat improvements in the Coeur d'Alene basin are varied. Seven project categories have been identified that could provide improved conditions for trout: 1) channel reconfiguration, 2) road and railway bed relocation, 3) mainstem bank structures, 4) wood additions, 5) culvert improvements, 6) side channel restoration, and 7) canopy restoration. Project feasibility should be considered in evaluating replacement alternatives [43 CFR § 11.82 (d)]. Overall, these types of projects are feasible, and similar types of projects have been implemented throughout the West. Elements relating to project design, implementation, and feasibility for each project type are discussed below.

Channel reconfiguration

Channel reconfigurations are typically implemented to recover stream habitat that has been heavily modified through ditching or otherwise relocating a stream away from a naturally occurring alignment. Channel reconfigurations involve relocating a stream into a more naturally occurring alignment, which may include excavating a new channel with characteristics similar to the predisturbed stream. Channel reconfiguration techniques affect the local slope, length, sinuosity, and dimensions of the channel and, as a result, alter basic channel processes. Because of the degree of modifications, these projects are very useful for accelerating recovery to a stable, sustainable channel form. Many projects of this type have been implemented successfully throughout the West. Photographs of a few examples are provided in Figures 4.15-4.17.

Figure 4.15. Spring Creek, South Dakota, channel relocation following highway re-alignment.

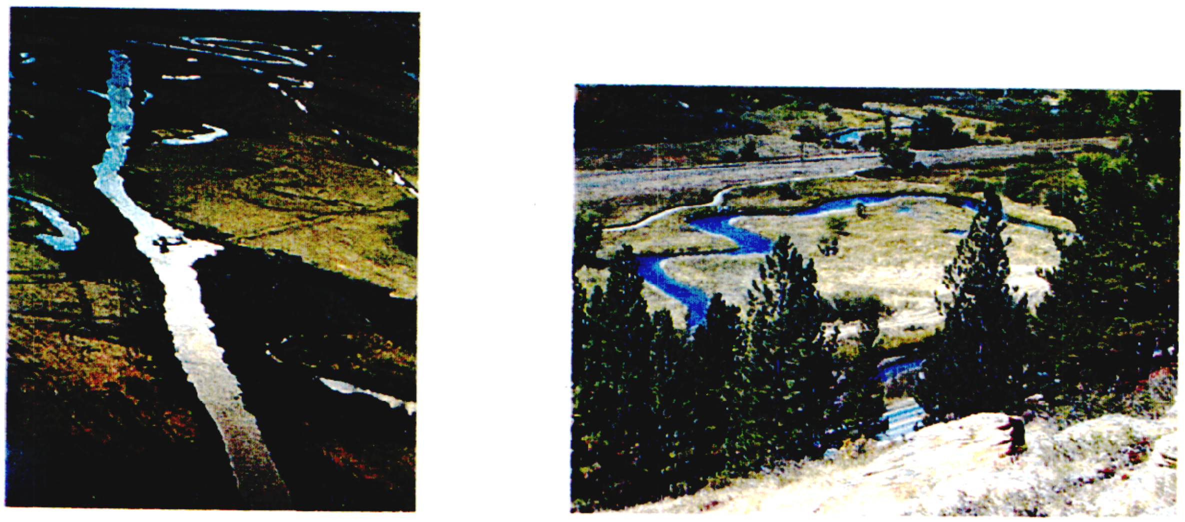


Figure 4.16. Big Spring Creek, Montana, channel relocation for habitat improvement.

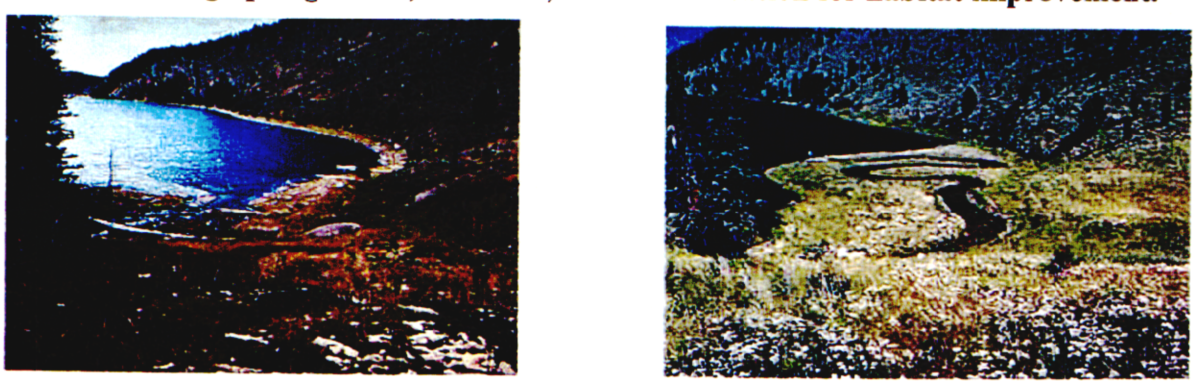


Figure 4.17. Wade Lake, Montana, spawning channel creation.

Construction of channel reconfiguration projects requires careful sequencing of work phases. Construction steps may include the following (not necessarily in this order): installing erosion and sediment control; providing access for and stockpiling imported materials, waste materials, and transitional redistributed materials; constructing a diversion channel; diverting stream flow; rescuing fishes from areas to be dewatered; dewatering; constructing the channel bed and streambanks; installing habitat features; and redirecting flow into the modified channel.

Road and railway bed relocation

This project type is referred to as road and railway bed *relocation* because removing the roadway without establishing or identifying an alternate route is sometimes not feasible. Therefore removing the road or railway, while desirable, may require construction or upgrades to existing travel ways in addition to simple removal of the offending road fill.

There are typically two types of road bed relocation/removal projects: roads or railways that require complete removal and those that require only partial removal of the fill. Complete removal is typically done on roads or railways that traverse flood plains or are in high risk geologic settings where failure of the fill is imminent. Partial removal is typically done at stream crossings where the road fill is on a hillside.

Road/railway bed removal involves removal of the road/railway bed to preconstruction topography, and the surface is ripped or otherwise treated to offset any compaction of the underlying soil. Care must be exercised in reestablishing hydraulic connection of back channels and high flow channels to ensure that proper grades and cross sectional shapes are constructed. The bare ground of the removed roadway can act as a pathway for avulsion, and steps to offset the relative hydraulic smoothness of the removed fill must be taken. These steps typically include planting of containerized trees and shrubs and placing large woody debris (LWD) in the cleared area. An example of this type of project is depicted in Figure 4.18.

Figure 4.18. Clear Creek, Oregon, removal and restoration of roadway on a floodplain.

Road/railway bed removal at stream crossings can require hydrologic and hydraulic modeling to ensure adequate replacement or construction of an at-grade streambed. While streambed material sizing can be inferred from materials in the streambed both upstream and downstream of the fill area, it is important to determine the relative mobility of these materials to safeguard against the potential for head cutting.

Many miles of roadway have been removed or otherwise modified in this way, and many examples can be found in National Forests throughout the Pacific Northwest.

Mainstem bank structures

Projects designed to provide bank erosion protection for stream banks vary in approach and material types. Typically projects can be grouped into those that protect against lateral erosion of the stream bank and those that protect against vertical incision. Protection in the vertical direction is important to those sites that have high banks of rather consolidated materials because these banks are subject to collapse and thus lateral retreat. Most projects deal with both lateral and vertical failure issues.

Lateral protection methods include revetments, barbs or groins, and bank pullback and revegetation. Revetments include a wide variety of techniques that may encompass the use or rock as riprap, woody materials as cribbing, engineered soil-encapsulated fills or combinations of these methods. Barbs or groins can also be constructed of a variety of materials ranging from riprap to LWD. Bank pullback methods are commonly employed along bank segments where the vertical nature of the bank and the change in water surface levels lead to bank collapse and failure.

It is generally accepted that high densities of wood found along channel margins in a given reach of stream lead to higher densities of trout and a greater diversity of channel features with associated aquatic communities. Because each of the general techniques described can incorporate LWD, we focus our discussion on techniques that incorporate wood elements into their overall design. Furthermore, stream bank protection techniques using rock alone are not very effective at recruiting wood, so incorporating LWD is important because it tends to collect other debris and encourages the recruitment of even more wood. For wood recruitment to occur properly, logs should be positioned so that a portion is above the flood-flow water surface. Floods make LWD available as they erode banks, drawing large and small trees into the active channel. Small trees and wood material added to the channel float downstream and are often captured by existing wood jams. If wood is installed too low on revetments, they will not collect this liberated debris as it floats by. The ideal solution is to have wood at various elevations on the bank to ensure recruitment at all flows. Some examples are provided in Figures 4.19-4.21.

- Mobilization of equipment and labor to and away from the construction job site.
- Design of the project, including completion of design plans and specifications.
- Completion of the necessary permitting documents for the project.
- Contingency for additional costs that are dependent on site-specific conditions. These additional costs arise from site-specific conditions such as the nature of the subsurface materials (e.g., presence of bedrock), the level of the groundwater table, the presence of contamination or artificial structures on site, site access limitations, and other project design restrictions that arise from site-specific considerations. These additional costs cannot be specified in advance at this phase of project cost estimation, but can only be specified once the project site has been selected, the site-specific conditions are characterized, and the project design considerations are better understood.

These costs are estimated as percentages of construction costs because they vary with the overall size or scope of the job. The percentages used for these cost items in this report are selected to represent the overall averages of these costs when the projects are implemented numerous times at numerous places. This approach to including these cost items as percentages of construction costs is a standard practice in the environmental restoration field.

Mainstem bank structures

Mainstem bank structure costs are presented in Table 4.11. Costs in this table were developed for a bank structure using wood and fabric lifts on a riprap rock foundation toe. For purposes of this estimate, the bank protection treatment was estimated for 100 feet of channel bank 3 feet high. This is a typical treatment for a reach of stream bank that is eroding badly and requires reconstruction. Reconstruction in this example involves a structural fill wrapped in geotextile fabric and reinforced with large woody debris on a foundation of riprap. Revegetation of the site assumes a 10 foot wide area the length of the project will be planted with trees, shrubs, and a grass seed mixture. Additional costs are estimated by a percentage of the construction cost. This results in a total project cost of approximately $90,000 for a 100 foot project, or approximately $4.6 million per mile.

Road and railway bed relocation

Costs for road/railway bed relocation projects are presented in Table 4.12. Costs can vary based on the size or volume of the fill removal and equipment access to the site. Generally projects can be accessed from one end of the removed road only, and this makes for a complicated sequencing process for getting supplies and materials in and removed materials out. The cost estimate presented in Table 4.12 is based on a typical roadway removal project involving removal of the roadway prism, recontouring of the floodplain, reconnection of back channels,

Table 4.11. Mainstem bank structure costs

Assumes 3 ft high bank		Length: 100 ft Width: 90 ft Cost/unit	Site units	Site cost
Streambank construction				
Excavate and stockpile		$10.00/yd^3	65	$650
Fill and compact		$10.00/yd^3	65	$650
Large woody debris placed		$450.00/ea	50	$22,500
Geotextile lift construction		$45.00/lin. ft	300	$13,500
Riprap placed		$50.00/yd^3	35	$1,750
Revegetation				
Trees/shrubs/seed		$1.00/ft^2	1,000	$1,000
Soil amendments		$0.25/ft^2	1,000	$250
Erosion control		$2.00/lin. ft	100	$200
Dewatering		$10,000.00/ea	1	$10,000
Construction cost				$50,500
Construction mob/demob	3%			$1,515
Design	20%			$10,100
Permitting	10%			$5,050
Contingency for additional site-specific costs	40%			$20,200
Total cost				$87,365
Cost per foot				$874
Cost per mile				$4,612,872

placement of large woody debris, and planting to develop the estimate presented. Additional costs are estimated as percentages of the construction cost. For a 100 foot section of road removal, the estimate results tallies a total project cost of approximately $21,000, or approximately $1.1 million per mile.

Channel reconfiguration

Unit costs for channel reconfiguration projects are presented in Table 4.13. Project costs will vary according to the size of the channel constructed. Key cost items regardless of channel size include dewatering systems, imported materials, heavy equipment, construction methods, and bank construction techniques. Dewatering may be a significant cost for many channel

Table 4.12. Road and railway bed relocation costs

Assumes 3 ft high road		Cost/unit	Site units	Site cost
		Length: 100 ft Width: 30 ft		
Excavation				
Excavate and disposal		$15.00/yd^3	335	$5,025
Construction staking		$1,000.00/ea	1	$1,000
Revegetation				
Trees/shrubs/seed		$1.00/ft^2	3,000	$3,000
Large woody debris placed		$450.00/ea	5	$2,250
Soil amendments		$0.25/ft^2	3,000	$750
Erosion control		$2.00/lin. ft	200	$400
Construction cost				$12,425
Construction mob/demob	3%			$373
Design	20%			$2,485
Permitting	10%			$1,243
Contingency for additional site-specific costs	40%			$4,970
Total cost				$21,495
Cost per foot				$214.95
Cost per mile				$1,134,949.20

reconfiguration projects because it requires, in most cases, complete dewatering of at least half the channel and often the entire constructed portion of the channel. In addition to dewatering during construction, there is a point in the construction where the new channel is watered up and the old channel is dewatered. Construction timing for this procedure is often strictly regulated because of the need to rescue fish and other aquatic species in the dewatered segment. The need to import materials for any component of the modification will greatly increase implementation costs. Many channel modification projects will require construction of stable channel banks. Costs associated with bank construction can be significant and also need to be considered.

The cost estimate in Table 4.13 is for a typical channel reconfiguration project that involves relocating 100 feet of a medium sized stream about 15 feet wide. The estimate includes costs for the excavation of the new channel, construction of both stream banks with a combination of large wood and geotextile reinforced soil lifts, placement of stream bed gravels, and planting of the new stream bank areas. Additional costs associated with design, permitting, and construction mobilization/demobilization are estimated as percentages of the overall construction cost. The total estimated cost for conducting the project on 100 feet of stream is approximately $110,000, or approximately $5.9 million per mile.

Table 4.13. Channel reconfiguration costs

Assumes a 3 ft deep channel		Cost/unit	Site units	Site cost
		Length: 100 ft Width: 15 ft		
Excavation				
Excavate and disposal		$15.00/yd^3	170	$2,550
Construction staking		$3,000.00/ea	1	$3,000
Streambank construction				
Excavate and stockpile		$10.00/yd^3	130	$1,300
Fill and compact		$10.00/yd^3	130	$1,300
Large woody debris placed		$450.00/ea	15	$6,750
Geotextile lift construction		$45.00/lin. ft	600	$27,000
Stream bed construction				
Gravel fill		$50.00/yd^3	150	$7,500
Finish grading		$2,000.00/ea	1	$2,000
Revegetation				
Trees/shrubs/seed		$1.00/ft^2	2,000	$2,000
Soil amendments		$0.25/ft^2	2,000	$500
Erosion control		$2.00/lin. ft	200	$400
Dewatering		$10,000.00/ea	1	$10,000
Construction cost				$64,300
Construction mobilization/demob	3%			$1,929
Design	20%			$12,860
Permitting	10%			$6,430
Contingency for additional site-specific costs	40%			$25,720
Total cost				$111,239
Cost per foot				$1,112.39
Cost per mile				$5,873,419.20

Wood additions

The costs of wood addition projects are presented in Table 4.14. Obtaining and buying wood is generally the biggest cost variable in a wood related habitat project. Large wood can often be readily purchased on the open market or directly from a private landowner, however, some projects have been able to obtain wood from donated sources. In either case, costs for retention of the root wad and transportation to the site must also be included. For purchased wood, these factors currently translate to costs of $400-600 per tree with/without root wad delivered to the site. Cost estimates for wood placement and anchoring can vary greatly depending on access,

Table 4.14. Wood addition costs

		Small channel			Medium channel			Large channel		
		Length: 100 ft Width: 6 ft			Length: 100 ft Width: 15 ft			Length: 100 ft Width: 90 ft		
Assumes 3 ft high bank		**Cost/unit**	**Site units**	**Site cost**	**Cost/unit**	**Site units**	**Site cost**	**Cost/unit**	**Site units**	**Site cost**
Log placements										
Excavate and stockpile		$10.00/CY	21	$210	$10.00/yd^3	28	$280	$10.00/CY	70	$700
Fill and compact		$10.00/CY	21	$210	$10.00/yd^3	28	$280	$10.00/CY	70	$700
Large woody debris placed		$450.00/ea	3	$1,350	$450.00/ea	4	$1,800	$450.00/ea	10	$4,500
Revegetation										
Trees/shrubs/seed		$1.00/ft^2	180	$180	$1.00/ft^2	240	$240	$1.00/ft^2	600	$600
Soil amendments		$0.25/ft^2	180	$45	$0.25/ft^2	240	$60	$0.25/ft^2	600	$150
Erosion control		$2.00/lin. ft	100	$200	$2.00/lin. ft	100	$200	$2.00/lin. ft	100	$200
Dewatering		$10,000.00/ea	1	$10,000	$10,000.00/ea	1	$10,000	$10,000.00/ea	1	$10,000
Construction cost				$12,195			$12,860			$16,850
Construction mob/demob	3%			$366			$386			$506
Design	20%			$2,439			$2,572			$3,370
Permitting	10%			$1,220			$1,286			$1,685
Contingency for additional site-specific costs	40%			$4,878			$5,144			$6,740
Total cost				$21,097			$22,248			$29,151
Cost per foot				$210.97			$222.48			$291.51
Cost per mile				$1,113,940			$1,174,684			$1,539,146

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mechanism of delivery, wood species availability and anchoring costs. Placing a log in a remote area with a helicopter is far more expensive than with an excavator standing on a road. Wood structures installed in remote sites often require considerable hand labor and can be very time consuming and expensive to assemble.

Estimates for a typical placement of wood in stream channels to provide habitat are provided separately in Table 4.14 for small, medium, and large streams. Each of these estimates assumes easy road side access and that 100 feet of channel is being treated with wood pieces 40 feet long and 18 inches in diameter. Other assumptions include the following:

- Wood pieces are installed by burial into the bank or streambed, cabled to each other and/or other available standing trees.
- Disturbed areas are reseeded with a combination of tree/shrub tubelings and grass seed.
- Dewatering is required for log placements as a measure to control construction generated sediment and turbidity.

Additional costs are estimated as percentages of the construction cost. For a 100 foot section of treated stream, the estimates range from approximately $21,000 for small streams to $29,000 for large streams, or $1.1 million to $1.5 million per mile.

4.3 Calculation of Damages

4.3.1 Scaling replacement costs

As described previously, the Trustees have calculated replacement costs to address both the loss of services compared to baseline conditions and interim losses of services, where interim losses are the losses resulting from the injury that occur until restoration to baseline is achieved [43 CFR § 11.83 (c)]. Interim losses account for the length of time over which the injury occurs: the more time required to achieve baseline restoration, the greater the interim losses. Damages for interim losses are added to damages for restoration to baseline.

The losses of surface water services can be compensated for by providing an equivalent amount of habitat service replacement. To account for interim loss, service losses are quantified as a function of the degree of service loss, the spatial extent of the service loss, and the time period of injury. The amount of habitat replacement necessary to offset the total loss is then "scaled" to provide an equivalent amount of service replacement. In this way, the habitat services gained through replacement offset the service losses resulting from the injury. The cost of the amount of habitat replacement necessary to offset the losses is then the measure of replacement damages.

The approach we used to scale replacement cost damages is the habitat equivalency analysis (HEA) procedure developed by NOAA. HEA has been applied by multiple resource trustees and responsible parties at many sites around the United States to determine the amount of restoration needed to compensate for injuries to natural resources. Restoration is scaled so that the ecological service gains provided at compensation sites equal the cumulative service losses at the injured site, including interim losses, where ecological services are defined as the physical, chemical, or biological functions that one natural resource provides for another (NOAA, 2000). Thus, HEA is used to determine the amount of restoration that is required to compensate for past, current, and future (i.e., residual to any cleanup) injuries and service losses. The technical approach for completing a HEA is presented in a series of published articles (e.g., Chapman et al., 1998; Peacock, 1999; NOAA, 2000; Strange et al., 2002; Strange et al., 2004; Allen et al., in press).

The technical approach used in the HEA calculations and the results of the analyses are presented in Section 4.3.2. The resulting damage calculations are presented in Section 4.3.3.

4.3.2 Technical approach to scaling replacement services

Reductions in surface water services that have resulted from injury and the expected future path of these reductions as a result of ROD-attributable actions are presented (using trout density as a metric for the degree of service reduction) in Section 4.1. Section 4.2 describes types of nonmining-related surface water habitat stressors, possible habitat enhancement alternatives that could reduce these stressors and thereby improve surface water services, the estimated benefits of project implementation in terms of increased trout densities, and the estimated recovery periods following project implementation.

The HEA used to scale replacement alternatives covers the period from 1981, the first full year following CERCLA authorization (December, 1980), through 2110, which is 100 years after 2010, the date we assume any habitat enhancement project would start. The HEA calculations of service loss are referred to as "debits." Increases in aquatic services from habitat enhancement actions are referred to as "credits."

To calculate the total surface water habitat services debit, we quantified the area of injured surface water and the time period over which surface water is injured. This service loss can be expressed as acre-years, reflecting both the spatial and temporal extent of loss. For example, 2 acres of surface water that each have been injured for one year can be quantified as 2 acre-years of service loss. Similarly, 1 acre that has been injured for two years could be quantified as 2 acre-years of service loss. To reflect the standard economic assumption of time preferences (i.e., a good received now is preferred to the same good received at some future date), a 3.0% discount rate was applied to all calculations performed across time to depict debits in present value terms. Figure 4.27 provides an illustration of this calculation of debits.

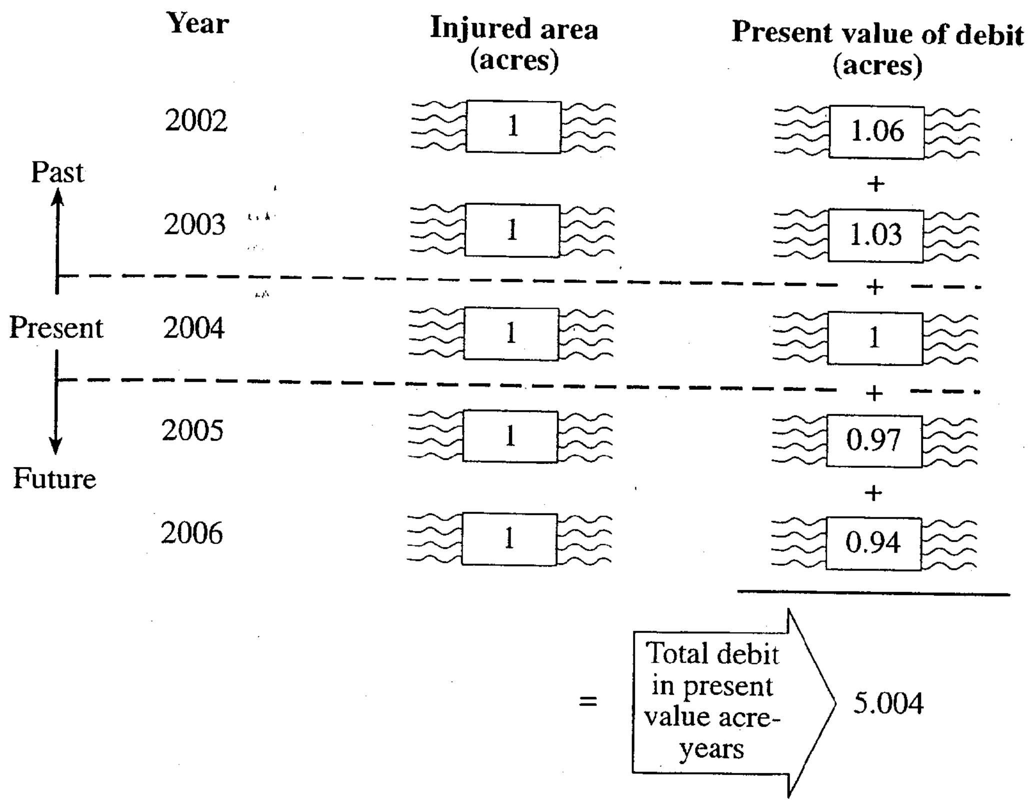

Figure 4.27. Illustrative depiction of calculating present value debits using a 3% discount rate for a 1-acre area of surface water injured from 2002 to 2006.

To calculate surface water habitat service credits, a similar type of approach is used. The total present value of service benefits achieved through habitat enhancements is calculated using the same discounting approach. The calculation of credits requires estimation of the time when habitat enhancement would start, the duration of project implementation, the time period over which replacement actions would take place, and the duration of recovery after the enhancement project has been completed. Figure 4.28 provides an illustration of the calculation of credits.

Table 4.15. Information used in calculating service loss debits

Reach	Time segment	Start year	Stop year	Trout density at start of period (#/100 m^2)	Trout density at end of period (#/100 m^2)	Baseline density (#/100 m^2)	% Baseline service at end of period	Reach area (acres)	Present value acre-years of debit
South Fork Coeur d'Alene River — Canyon Creek mouth to North Fork									
	1	1981	2004	2	2	11.8	17%	114	3,264
	2	2005	2032	2	3	11.8	25%		1,725
	3	2033	2110	3	3	11.8	25%		977
Total									**5,966**
Ninemile Creek — below Success mine to mouth									
	1	1981	2004	0	0	12.2	0%	6.3	216
	2	2005	2032	0	0	12.2	0%		116
	3	2033	2110	0	0	12.2	0%		74
Total									**406**
Ninemile Creek — Interstate mine to Success mine									
	1	1981	2004	0	0	12.2	0%	2.4	81
	2	2005	2032	0	3.1	12.2	25%		44
	3	2033	2110	3.1	3.1	12.2	25%		28
Total									**153**
Canyon Creek — Oneil Gulch to mouth									
	1	1981	2004	0	0	5.5	0%	20.3	700
	2	2005	2032	0	0	5.5	0%		381
	3	2033	2110	0	0	5.5	0%		267
Total									**1,348**

The present value service losses calculated for SFCDR, Ninemile Creek, and Canyon Creek are 5,966, 559, and 1,348 acre-years, respectively.

Replacement project credit calculations

Table 4.16 presents the information used in calculating credits for the habitat enhancement projects and the results of the calculations in present value acre-years. To calculate these credits, we estimated that enhancement activities would begin in 2010. Project construction would last for one year (until the start of 2011), followed by a 10-year recovery period. Because large-scale project implementation in the basin cannot reasonably occur in a single year, we assumed two different implementation periods: a five-year period (i.e., 20% of the enhancement projects would be initiated in each of five successive years) and a 10-year period (10% of the enhancement projects would be initiated in each of 10 successive years).

Table 4.16. Information used in calculating service gain credits

Project type	Gain in trout production at end of period (#/100 m^2)	Present value credit generated per acre of enhancement project (acre-years)	
		5-yr implementation	10-yr implementation
Woody debris addition, road relocation, mainstem bank structure small channels	13.5	21.7	20.1
Channel reconfiguration[a]	30.9	49.9	46.2

a. Channel reconfiguration is assumed to double the acreage of available habitat because stream sinuosity is increased. The gain in trout production results from an increase in both habitat quality and quantity.

The benefits of enhancement projects rely on the information provided in Section 4.2.4, in which it is estimated that a net addition of 13.5 trout per 100 m^2 would be produced through project implementation, with full project benefits achieved over a 10-year recovery period. As noted previously, for channel reconfiguration, the total benefit is estimated by including both the increase in stream area achieved through increasing stream sinuosity and the increase in trout density.

Determination of amount of necessary habitat enhancement

The total debit, in present value acre-years, of each injured stream segment was shown in Table 4.15 and the total credit, also in present value acre-years, was shown in Table 4.16. To calculate the amount of habitat enhancement necessary to offset the debit, the total service loss (in present value acre-years) for each injured reach was divided by the per-acre credit of habitat replacement and then adjusted down to account for the relatively greater productivity of the

Service replacement damages for the South Fork Coeur d'Alene are larger than those for Canyon or Ninemile creeks because the extent of injury and associated service losses are greater. Depending on the implementation period and project type, damages range from $34 million to $110 million (Table 4.20).

Table 4.20. Results of service replacement damage calculations: South Fork Coeur d'Alene River (millions of 2004 dollars)

Implementation scenario	Habitat enhancement project type	
	Woody debris addition: large river	Mainstem bank structure
10-year	$36.7	$110.0
5-year	$34.0	$101.9

Cumulative damages for the three injured areas can be calculated by summing the individual damage estimates. The low estimate of cumulative damages can be obtained by adding the least-cost project alternatives for each injured stream. The high estimate of cumulative damages can be obtained by adding the highest cost project alternatives for each injured stream. As shown in Table 4.21, total replacement damages for the 10-year implementation scenario range from $69.5 million to $192 million and from $64.4 million to $177.9 million for the 5-year implementation scenario. These values are likely underestimated service replacement damages because no service losses for injured surface waters of the lower Coeur d'Alene basin and Lake Coeur d'Alene are included.[1]

Table 4.21. Total service replacement damages (millions of 2004 dollars) for Canyon Creek, Ninemile Creek, and the South Fork Coeur d'Alene River for 10- and 5-year implementation scenarios. The low estimate is calculated by summing lowest cost replacement project alternatives. The high estimate is calculated by summing the highest cost replacement project alternatives.

Implementation scenario	Low estimate	High estimate
10-year	$69.5	$192.0
5-year	$64.4	$177.9

1. As noted previously, work related to this issue is ongoing and we reserve the right to modify our opinions. Conceptually, such an analysis could be undertaken by estimating the degree of service losses using the relationship between ALC exceedences and trout populations (in Section 4.1) and applying service losses to the areal extent of injury.

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Wesche, T.A. 1985. Stream channel modifications and reclamation structures to enhance fish habitat. In *The Restoration of Rivers and Streams*, J.A. Gore (ed.). Butterworth Publishers, Boston, MA, pp. 103-163.

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Appendix — Resumes

David J. Chapman
Joshua Lipton
Greg Koonce
Frank J. Rahel

David J. Chapman

Employment History

- Managing Economist, Stratus Consulting Inc., Boulder, CO, 2003-present
- Chief, Pacific Coast Branch, Damage Assessment Center, NOAA, 2000-2003; Acting Chief, 1999-2000
- Economist, Damage Assessment Center, NOAA, 1993-1999
- Consultant, California Department of Fish and Game, 1992-1993
- Consultant, Foster Associates, San Francisco, CA, 1992
- Consultant, State of California Department of Fish and Game, 1990-1993
- Research Consultant, NRDA Inc., San Diego, CA, 1989-1992
- Research Consultant, Minerals Management Service/University of Washington, Department of Forestry, 1989
- Research Consultant to Dr. W. Michael Hanemann (UC Berkeley), 1985-1986
- Graduate Student Instructor, University of California Berkeley, 1985-1991

Education

- University of California, Irvine, BA, Economics, 1983
- University of California, Berkeley, MS, Natural Resource Economics, 1990 (with PhD studies)

Professional Experience

Mr. Chapman has 18 years of experience in natural resource valuation and policy analysis, specializing in behavioral and welfare effects of environmental and natural resource impacts and federal environmental policy. He is experienced in the technical development and implementation of non-market valuation studies to measure the welfare effects of environmental contamination. In addition, Mr. Chapman has coordinated the development and evaluation of federal and state environmental policies and assisted in the development of federal regulations. He has over 10 years of experience working in the federal government conducting natural resource damage assessments (NRDAs), policy evaluation, and regulation development.

At Stratus Consulting, Mr. Chapman leads NRDA projects for both state and federal clients, is leading projects on non-market valuation studies including the valuation of coral reefs and improved weather information, and has worked on the conceptual and empirical estimates of the value of water for the American Water Works Research Foundation.

As Pacific branch chief for NOAA's Damage Assessment Center, Mr. Chapman's responsibilities covered the region from Alaska to California, and the Pacific Islands. He was responsible for the overall management of all scientific and economic studies conducted in support of multiple NRDAs for oil spills and toxic waste sites. Activities included spill response coordination, case strategy, technical assessment guidance, quality assurance, and management of eight technical and administrative staff members. Activities also included the role of senior economist on NOAA research projects.

Mr. Chapman served as the lead NOAA economist on over 20 NRDAs as well as methods development and training of in-house and state and federal agency personnel on economic methods.

Mr. Chapman's experience includes the following:

- Served as expert witness to the California Department of Fish and Game on oil spill valuation, and supported the California Office of Attorney General to measure recreation losses resulting from the *American Trader* oil spill, including depositing and testifying at trial (1997).
- Served as expert consultant on the *Avila Beach* oil spill NRDA responsible for data collection on response to spill and human use of site, development of assessment research plan, implementation of assessment, and authoring expert report, and participated in settlement negotiations.
- Provided economic analysis on consultant projects dealing with industrial and commercial sector water conservation practices, and measuring economic impact of proposed Bay Area Rapid Transit extension through the City of Fremont, California.
- Developed fair market valuation study for fiber optic cable right of way through National Marine Sanctuaries.
- Supported economic damage assessment for the *Exxon Valdez* oil spill NRDA.
- Developed economic analysis to estimate the impact of oil and gas development along the Oregon and Washington coasts, including development of a contingent valuation survey.
- Supported economic impact of proposed agricultural wastewater discharges into the San Joaquin River, recreational assessment for the albacore sport fishing economic and marine recreational fishing studies.

Selected Articles/Reports

Allen, P.D., D.J. Chapman, and D. Lane. "Scaling Environmental Restoration to Offset Injury Using Habitat Equivalency Analysis." In *Integrating Ecologic Assessment of Economics to Manage Watershed Problems,* R.J.F. Bruins and M. Heberlein (eds.). CRC Press, Boca Raton, FL. Forthcoming.

Chapman, D. and B. Julius. 2004. "The Use of Preventative Projects as Compensatory Restoration." Forthcoming in *Journal of Coastal Research.*

Chapman D. and W.M. Hanemann. 2001. "Environmental Damages in Court: The *American Trader* Case." In *The Law and Economics of the Environment*, Anthony Heyes (ed.), pp. 319-367.

Chapman, D. and E. English. 2001. Fair Market Value Analysis for a Fiber Optic Cable Permit in National Marine Sanctuaries. Report to National Marine Sanctuary Program, National Oceanic and Atmospheric Administration, Silver Spring, MD.

Chapman, D., N. Iadanza, and T. Penn. 1998. *"Calculating Resource Compensation: An Application of the Service-to-Service Approach to the Blackbird Mine Hazardous Waste Site."* National Oceanic and Atmospheric Administration Damage Assessment and Restoration Program Technical Paper 97-1. October.

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Kanninen, B., D. Chapman, and W.M. Hanemann. 1992. Survey Data Collection; Detecting and Correcting for Biases in Responses to Mail and Telephone Surveys. In *Proceedings of the U.S. Census Bureau's Annual Research Conference.*

Ellis, G., D. Chapman, and N. Johnson. 1991. Assessing the Economic Impact to Coastal Recreation and Tourism from Oil and Gas Development in the Oregon and Washington Outer Continental Shelf. OCS Study MMS 91-0046. May.

Hanemann, M., E. Lichtenberg, D. Zilberman, D. Chapman, L. Dixon, G. Ellis, and J. Hukkinen. 1987. Economic Implications of Regulating Agricultural Drainage to the San Joaquin River. Regulation of Agricultural Drainage to the San Joaquin River. SWRCB Order No. W.Q. 85-1,

Technical Committee Report. Appendix G (two vols.). State Water Resources Control Board, Sacramento, California.

Presentations/Short Courses/Working Papers

"The Use of Preventative Projects as Compensatory Restoration" Restore America's Estuaries Conference, Baltimore, MD, April 2003.

"Developing Defensible NRDA Claims" Short Course. International Oil Spill Conference. Vancouver, British Columbia Canada. April 2003.

"Non-Market Valuation Techniques in Natural Resource Damage Assessments." Invited Lecture Series. Department of Economics, College of William and Mary, Williamsburg, VA. Spring 2003.

"NOAA's Blue Ribbon Panel: 10 Years After" Invited Panelist. Resources for the Future, Washington, D.C. November 2002.

"Cooperative NRDA Assessments." Short course. International Oil Spill Conference, Tampa Bay. March 2001.

"The Role of Natural Resource Economics in the *American Trader* Oil Spill Trial." Invited speaker at the Yosemite Law Institute, Yosemite, CA. October 1998.

"Using Economics in the Courts" Presentation to the Southern Economic Association Meeting, Baltimore, MD. October 1998.

"Use of Habitat Equivalency Analysis in Natural Resource Damage Assessments." Presentation to the Joint Assessment Team, Portland, OR. June 1996.

"Non-Market Valuation Using Contingent Behavior: Model Specification and Consistency Tests." Presented at the 1996 Annual AERE Workshop, Tahoe City, CA. June 1996.

"Resource Compensation: An Application of Northwest Salmon" Presented at the W-133 Annual Meetings, Jekyll Island, GA. March 1996.

"Natural Resource Economics" Presented to the Natural Resource Damage Assessment and Restoration Workshop, Sponsored by USFWS. April 1994.

Chapman, D., and W.M. Hanemann. "*Correlated Discrete-Response Contingent Valuation*" Department of Agricultural and Resource Economics, Working Paper, University of California. Berkeley. July, 1993.

Hanemann, W.M., D. Chapman, and B. Kanninen. *"Non-Market Valuation Using Contingent Behavior: Model Specification and Consistency Tests."* Department of Agricultural and Resource Economics, Working Paper, University of California. Berkeley. January 1993.

"Survey Data Collection: Detecting and Correcting for Biases in Responses to Mail and Telephone Surveys." (co-authored with B. Kanninen) Presented at the United States Census Bureau's Conference on Statistical Methods, Washington D.C. March 1992.

"Empirical Uses of Contingent Valuation Studies in Natural Resource Damage Assessments." Presented to Department of Forestry, University of Washington. July 1989.

Hanemann, W.M., D. Chapman. *"Beyond Contingent Valuation: Deriving Environmental Benefits from Hypothetical Data."* Department of Agricultural and Resource Economics, Working Paper, University of California, Berkeley. October, 1988.

"Beyond Contingent Valuation: Deriving Environmental Benefits from Hypothetical Behavior Data." (co-authored with W.M. Hanemann) Presented at the American Public Policy Association Meeting, Washington, D.C. October 29, 1987.

Litigation Experience/Testimony

Montrose Superfund Site, 2000. Expert witness preparation and deposition support.

American Trader Oil Spill, 1990. Expert witness, report development, and deposition and trial testimony.

NOAA Facilitation and Mediation Training Workshop June 1998.

Advanced Quantitative Marketing Methods, Haas Business School, UC Berkeley, July 30-August 1, 1997.

Stated Preference Short Course. Portland State University. June 24-27, 1996.

Qualitative Choice Methods Workshop. UC Berkeley May 4-8, 1992.

Affiliations

- Association of Environmental and Resource Economics
- American Economic Association

Joshua Lipton

Employment History

- Chief Executive Officer, 2001-present; Stratus Consulting, Boulder, CO, Executive Vice President, 1998-2000
- Vice President, Hagler Bailly Inc. and RCG/Hagler Bailly (predecessor firm), Boulder, CO
- Environmental Analyst, Abt Associates Inc., Cambridge, MA
- Fisheries Biologist, Alaska State Dept. of Fish and Game, Soldotna, AK
- Research Assistant, Deutsche British Petroleum, A.G., Hamburg, Germany

Education

- Cornell University, PhD, Natural Resources
- Cornell University, MS, Natural Resources
- Middlebury College, BA, Ecology

Professional Experience

Dr. Lipton, CEO of Stratus Consulting, supervises the firm's environmental sciences and natural resources group, as well as its natural resource damage assessment (NRDA) practice.
Dr. Lipton's expertise includes scientific and policy issues related to environmental toxicology, natural resource damage assessment, ecology, natural resources investigations, and environmental chemistry. He has designed and directed laboratory and field toxicity tests, environmental sampling/monitoring studies, ecological field investigations, fisheries and wildlife population monitoring studies, and environmental modeling projects. Dr. Lipton has published peer-reviewed articles in scientific journals such as the *Canadian Journal of Fisheries and Aquatic Sciences*, *Environmental Toxicology and Chemistry*, *Aquatic Toxicology*, *Ecotoxicology*, *Transactions of the American Fisheries Society*, *Environmental Management*, and *Regulatory Toxicology and Pharmacology*. Dr. Lipton has served as an elected member of the editorial board of *Environmental Toxicology and Chemistry* and *The Science of the Total Environment*.

Publications

Hansen, J.A., J. Lipton, P.G. Welsh, D. Cacela, and B. MacConnell. 2004. Reduced growth of rainbow trout (*Oncorhynchus mykiss*) fed a live invertebrate diet pre-exposed to metal-contaminated sediments. *Environmental Toxicology and Chemistry*. 23:1902-1911.

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Hansen, J.A., P.G. Welsh, J. Lipton, and M. Suedkamp. 2002. The effects of long-term cadmium exposure on the growth and survival of juvenile bull trout (*Salvelinus confluentus*). *Aquatic Toxicology* 58:165-174.

Hansen, J.A., J. Lipton, P.G. Welsh, D. Cacela, and A.D. Dailey. 2002. The relative sensitivity of bull trout (*Salvelinus confluentus*) and rainbow trout (*Oncorhynchus mykiss*) to acute exposures of cadmium and zinc. *Environmental Toxicology and Chemistry* 21:67-75.

Hansen, J.A., J. Lipton, P.G. Welsh, J. Morris, D. Cacela, and M.J. Suedkamp. 2002. Relationship between exposure duration, tissue residues, growth, and mortality in rainbow trout (*Oncorhynchus mykiss*) juveniles sub-chronically exposed to copper. *Aquatic Toxicology* 58:175-188.

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Strange, E., H. Galbraith, S. Bickel, D. Mills, D. Beltman, and J. Lipton. 2002. Determining ecological equivalence in service-to-service scaling of salt marsh restoration. *Environmental Management* 29:290-300.

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Barron, M.G., M. Anderson, D. Cacela, J. Lipton, S.J. Teh, D.E. Hinton, J.T. Zelikoff, A.L. Dikkeboom, D.E. Tillitt, M. Holey, and N. Denslow. 2000. Association between PCBs, liver lesions, and biomarker responses in adult walleye (*Sitzostedium vitreum vitreum*) Collected from Green Bay, Wisconsin. *Journal of Great Lakes Research* 26:250-271.

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Marr, J.C.A., J. Lipton, D. Cacela, J.A. Hansen, J.S. Meyer, and H.L. Bergman. 1999. Bioavailability and Acute Toxicity of Copper to Rainbow Trout in the Presence of Organic Acids Simulating Dissolved Organic Carbon. *Canadian Journal of Fisheries and Aquatic Sciences* 56:1471-1483.

Lipton, J., D. Cacela, C. Cowan, P. DeFur, L. Ginzburg, and C. Mebane. 1998. Risk characterization. In *Ecological Risk Assessment Decision-Support System: A Conceptual Design. Proceedings of the Pellston Workshop on Ecological Risk Assessment Modeling 23-28 August 1994.* K.H. Reinert, S.M. Bartell, and G.R. Biddinger (eds.). SETAC Press, Pensacola, FL.

Marr, J.C.A., J.A. Hansen, J.S. Meyer, D Cacela, T. Podrabsky, J. Lipton, and H.L. Bergman. 1998. Toxicity of cobalt and copper to rainbow trout: Application of a mechanistic model for predicting survival. *Aquatic Toxicology* 43:225-238.

Mastrine, J.A., A.S. Maest, J. Lipton, and B. Sanders. 1998. Framework for a nationwide hard rock mining database. In *Proceedings of the 32nd Meeting of the Geoscience Information Society,* C.J. Manson, (ed.). Geoscience Information Society, Washington, DC.

Anderson, M.J., M.G. Barron, S.A. Diamond, J. Lipton, and J.T. Zelikoff. 1997. Biomarker selection for restoration monitoring of fishery resources. In *Environmental Toxicology and Risk Assessment, Modeling and Risk Assessment, 6th Volume.* F.J. Dwyer, T.R. Doane, and M.L. Hinman (eds.). ASTM STP 1317, American Society for Testing and Materials, Philadelphia, PA.

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Marr, J.C.A., J. Lipton, D. Cacela, J.A. Hansen, H.L. Bergman, J.S. Meyer, and C. Hogstrand. 1996. Relationship between copper exposure duration, tissue copper concentration, and rainbow trout growth. *Aquatic Toxicology* 36:17-30.

DeLonay, A.J., E.E. Little, J. Lipton, D. Woodward, and J. Hansen. 1995. Avoidance response as evidence of injury: The use of behavioral testing in support of natural resource damage assessments. In *Environmental Toxicology and Risk Assessment.* T.W. LaPoint, F.T. Price, and E.E. Little (eds.). American Society for Testing and Materials, Philadelphia, PA.

Galbraith, H., K. LeJeune, and J. Lipton. 1995. Metal and arsenic impacts to soils, vegetation communities, and wildlife habitat in southwest Montana uplands contaminated by smelter emissions: I. Field evaluation. *Environmental Toxicology and Chemistry* 14(11):1895-1903.

Kapustka, L., J. Lipton, H. Galbraith, D. Cacela, and K LeJeune. 1995. Metal and arsenic impacts to soils, vegetation communities, and wildlife habitat in southwest Montana uplands contaminated by smelter emissions: II Laboratory phytotoxicity studies. *Environmental Toxicology and Chemistry* 14(11):1905-1912.

Lipton, J., D. Shaw, J. Holmes, and A. Patterson. 1995. Short communication: Selecting input distributions for use in Monte Carlo simulations. *Regulatory Toxicology and Pharmacology* 21:192-198.

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Phillips, G. and J. Lipton. 1995. Injury to aquatic resources caused by metals in Montana's Clark Fork River Basin: Historic perspective and overview. *Canadian Journal of Fisheries and Aquatic Sciences* 52:1990-1993.

MacRae, R., J. Meyer, A. Maest, and J. Lipton. 1994. Linking geochemistry and fish toxicology at mining sites: Determination of an organic acid analogue for use in copper toxicity studies on salmonids. *EOS* 75(44):243.

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Lipton, J. and H. Galbraith. 1993. Treatment of Uncertainty in Ecological Risk Assessment: Be Careful What You Wish for. *Water Quality Standards in the 21st Century*. U.S. EPA, Washington, DC.

Lipton, J., H. Galbraith, J. Burger, and D. Wartenburg. 1993. A paradigm for ecological risk assessment. *Environmental Management* 17:1-5.

Lipton, J. and J.W. Gillett. 1992. Uncertainty in risk assessment: Exceedence frequencies, acceptable risk, and risk-based decision making. *Regulatory Toxicology and Pharmacology* 15:51-61.

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Selected Presentations

Hansen, J.A., J. Lipton, P.G. Welsh, and D. Cacela. 2002. Exposure of Rainbow Trout to Live Invertebrate Diets Pre-Exposed to Metal-Contaminated Sediments. Poster presented at the 23rd Annual Meeting of the Society of Environmental Toxicology and Chemistry, Salt Lake City, UT. November 16-20.

Lipton, J., J.A. Hansen, and D. Cacela. 2002. Assessing Risks of Metal Contaminated Sediments to Trout: Diet Toxicity Studies. Platform presented at the 12th Annual Meeting of SETAC-Europe, Vienna, Austria. May 12-16.

Lipton, J., J.A. Hansen, T. Podrabsky, and K. LeJeune. 2001. Evaluation of Toxic Effects of Metals to Fish in the Coeur d'Alene River Basin, ID. Poster presented at the 22nd Annual Meeting of the Society of Environmental Toxicology and Chemistry, Baltimore, MD. November 11-15.

Lipton, J., J.A. Hansen, P.G. Welsh, and D. Cacela. 2001. Relationship between Whole-Body Copper Residues and Growth Effects in Two Salmonids. Platform presented at the 22nd Annual Meeting of the Society of Environmental Toxicology and Chemistry, Baltimore, MD. November 11-15.

Beltman, D.J., J. Lipton, and S. Bickel. 2001. A Review of Field Studies on PCB Impacts to Birds in Green Bay, Lake Michigan, USA. Poster presented at 11th Annual Meeting of SETAC-Europe, Madrid, Spain. May 6-10.

Hansen, J.A., P.G. Welsh, K. Neptun, and J. Lipton. 2001. Approaches to Evaluating Effects of Metal-Contaminated Sediments on Rainbow Trout. Platform presented at 11th Annual Meeting of SETAC-Europe, Madrid, Spain. May 6-10.

Lipton, J., M. Anderson, A. Grêt, D. Cacela, and D.J. Beltman. 2001. Evaluation of Biomarker Responses of Smallmouth Bass Collected from a PCB-Contaminated River. Poster presented at 11th Annual Meeting of SETAC-Europe, Madrid, Spain. May 6-10.

Lipton, J., J.A. Hansen, and P.G. Welsh. 2000. Are Water Quality Criteria for Metals Protective of Pacific Northwest Salmonids? Platform presentation at the 21st Annual Meeting of the Society of Environmental Toxicology and Chemistry, Nashville, TN. November 12-16.

Welsh, P.G., J. Lipton, and J.A. Hansen. 2000. Determining Site-Specific Bioavailability and Toxicity of Metals to Aquatic Biota. Platform presentation at the 21st Annual Meeting of the Society of Environmental Toxicology and Chemistry, Nashville, TN. November 12-16.

Hansen, J.A., J. Lipton, and P.G. Welsh. 2000. Subchronic Toxicity of Cadmium to Bull Trout. Platform presentation at the 21st Annual Meeting of the Society of Environmental Toxicology and Chemistry, Nashville, TN. November 12-16.

Hansen, J.A., P.G. Welsh, and J. Lipton. 2000. Relationship between Copper Exposure, Growth, and Tissue Accumulation in Rainbow Trout and Bull Trout during Subchronic Exposures. Platform presentation at the 21st Annual Meeting of the Society of Environmental Toxicology and Chemistry, Nashville, TN. November 12-16.

Lipton, J., J.A. Hansen, P.G. Welsh, and D. Cacela. 2000. Critical Body Residues for Metals: Evaluation of Relationship between Copper Accumulation and Effects in Rainbow and Bull Trout. Poster presented at the 21st Annual Meeting of the Society of Environmental Toxicology and Chemistry, Nashville, TN. November 12-16.

Welsh, P.G., J.A. Hansen, and J. Lipton. 2000. Acute Toxicity and Relative Sensitivity of Bull Trout and Rainbow Trout to Cadmium and Zinc. Poster presented at the 21st Annual Meeting of the Society of Environmental Toxicology and Chemistry, Nashville, TN. November 12-16.

Hansen, J.A., M. Barron, and J. Lipton. 2000. A Review of Critical Body Residues Found in the Literature. Poster presented at the 21st Annual Meeting of the Society of Environmental Toxicology and Chemistry, Nashville, TN. November 12-16.

Beltman, D.J., J. Lipton, and S. Bickel. 2000. A Comprehensive Review of Field Studies on PCB Impacts to Birds in Green Bay, Lake Michigan. Poster presented at the 21st Annual Meeting of the Society of Environmental Toxicology and Chemistry, Nashville, TN. November 12-16.

Beltman, D., J. Lipton, and S. Bickel. 2000. Evaluation of Adverse Effects of PCB Exposure on Fish Health and Reproduction in Green Bay, Lake Michigan. Presented at the 21st Annual Meeting of Society of Environmental Toxicology and Chemistry, Nashville, TN. November 12-16.

Hansen, J.A., J. Lipton, and P.G. Welsh. 2000. Acute Responses of Bull Trout (*Salvelinus confluentus*) to Cadmium, Copper, and Zinc. Poster presented at the Third SETAC World Congress 10th Annual Meeting of SETAC-Europe, Brighton, UK. May 21-25.

Hansen, J.A., J. Lipton, and P.G. Welsh. 2000. Effects of Cadmium and Copper on Bull Trout (*Salvelinus confluentus*) in Subchronic Exposures. Poster presented at the Third SETAC World Congress 10th Annual Meeting of SETAC-Europe, Brighton, UK. May 21-25.

Lipton, J., D. Beltman, and S. Bickel. 2000. Evaluation of Adverse Effects of PCB Exposure on Health and Reproduction on Fish in Green Bay, Lake Michigan (USA). Presented at the Third SETAC World Congress 10th Annual Meeting of SETAC-Europe, Brighton, UK. May 21-25.

Lipton, J., J.A. Hansen, P.G. Welsh, and D. Cacela. 2000. Relationship between Water Exposure, Tissue Residues, Growth, and Mortality of Rainbow Trout (*O. mykiss*) Exposed to Copper. Poster presented at the Third SETAC World Congress 10th Annual Meeting of SETAC-Europe, Brighton, UK. May 21-25.

Welsh, P.G., G. Chapman , J.A. Hansen, and J. Lipton. 2000. Ionic Composition of Reconstituted Laboratory Water and Natural Surface Waters in the United States — Implications for Conducting and Interpreting Metal Toxicity Tests. Presented at ASTM Tenth Symposium on Environmental Toxicology and Risk Assessment, Toronto, Ont., April 9-13.

Anderson, M., M.G. Barron, D. Beltman, D. Cacela, J. Lipton, S.J. Teh, D.E. Hinton, J.T. Zelikoff, A.L. Dikkeboom, D.E. Tillitt, M. Holey, and N.D. Denslow. 1999. Association between PCBs, Liver Lesions, and Biomarker Response in Adult Walleye (*Stizostedium vitreum vitreum)* Collected from Green Bay. Presented at the 20th Annual Meeting of Society of Environmental Toxicology and Chemistry, Philadelphia, PA. November 14-18.

Beltman, D., J. Lipton, D. Cacela, and S. Bickel. 1999. Spatial and Temporal PCB Patterns in Green Bay, Wisconsin. Presented at the 20th Annual Meeting of Society of Environmental Toxicology and Chemistry, Philadelphia, PA. November 14-18.

Hansen, J.A., P.G. Welsh, J. Lipton, and T. Podrabsky. 1999. Acute Toxicity and Relative Sensitivity of Bull Trout (*Salvelinus confluentus*) to Copper. Presented at the Annual Meeting of the Society of Environmental Toxicology and Chemistry, Philadelphia, PA. November 14-18.

Lipton, J. 1999. Natural Resource Damage Assessment in the United States. Presentation at the 9th Annual Meeting of Society of Environmental Toxicology and Chemistry-Europe, Leipzig, Germany, May 25-29. Prepared by Stratus Consulting Inc., Boulder, CO.

Lipton, J., P.G. Welsh, and J.A. Hansen, 1999. Influence of Mediating Biological Factors in Assessing Copper Risks to Aquatic Biota. Presented at the 20th Annual Meeting of Society of Environmental Toxicology and Chemistry, Philadelphia, PA. November 14-18.

Lipton, J., P. Welsh, J. Hansen, and S. Teh. 1999. Synergistic Toxicity of Copper and the Protozoan *Ichthyobodo sp.* to Rainbow Trout, *Oncorhynchus mykiss*. Presentation at the

9th Annual Meeting of Society of Environmental Toxicology and Chemistry-Europe, Leipzig, Germany, May 25-29. Prepared by Stratus Consulting Inc., Boulder, CO and the University of California, Davis.

Lipton, J., P. Welsh, T. Podrabsky, and J. Hansen. 1999. Approaches to Evaluating Copper Risks to Aquatic Biota. Presentation at the 9th Annual Meeting of Society of Environmental Toxicology and Chemistry-Europe, Leipzig, Germany, May 25-29. Prepared by Stratus Consulting Inc., Boulder, CO.

Lipton, J., P. Welsh, J. Hansen, T. Podrabsky, and R. Playle. 1999. Laboratory Studies Evaluating Biotic Ligand Models of Copper Toxicity to Rainbow Trout, *O. mykiss:* Gill Uptake Experiments. Presentation at the 9th Annual Meeting of Society of Environmental Toxicology and Chemistry-Europe, Leipzig, Germany, May 25-29. Prepared by Stratus Consulting Inc., Boulder, CO and Wilfrid Laurier University, Waterloo, Canada.

Strange, E., H. Galbraith, D. Beltman, R. Jones, and J. Lipton. 1999. Ecological Maturation in Restored Salt Marshes. Presented at the 20th Annual Meeting of Society of Environmental Toxicology and Chemistry, Philadelphia, PA. November 14-18.

Strange, E., H. Galbraith, D. Beltman, R. Jones, and J. Lipton. 1999. Restoration of Coastal Salt Marshes; "What is Success?" Presented at the 20th Annual Meeting of Society of Environmental Toxicology and Chemistry, Philadelphia, PA. November 14-18.

Welsh, P.G., J. Lipton, J.A. Hansen, and T. Podrabsky. 1999. Derivation of Gill Residue Threshold Values for the Biotic Ligand Model. Presented at the 20th Annual Meeting of Society of Environmental Toxicology and Chemistry, Philadelphia, PA. November 14-18.

Barron, M.G., R. Playle, P. Welsh, and J. Lipton. 1998. Calcium-Dependent Accumulation of Zinc on Rainbow Trout Gills. Presented at the Society of Toxicology, New Orleans, LA. March.

Cacela, D., D. Beltman, and J. Lipton. 1998. Determining Similarity among PCB Congener Profiles from Sediment Samples Using a Simple Multivariate Distance Sample. Presented at Society of Environmental Toxicology and Chemistry 19th Annual Meeting, Charlotte, NC. November 15-19.

Cacela, D., D. Beltman, and J. Lipton. 1998. Using PCB Congener Patterns to Identify PCB Sources. Presented at the Society of Environmental Toxicology and Chemistry 19th Annual Meeting, Charlotte, NC. November 15-19.

Lipton, J. 1998. Injury Endpoint Selection in Natural Resource Damage Assessment. Society of Environmental Toxicology and Chemistry 19th Annual Meeting, Charlotte, NC. November 15-19.

Lipton, J. and P.G. Welsh. 1998. Conducting Laboratory Studies to Evaluate the Site-Specific Toxicity of Cu. Society of Environmental Toxicology and Chemistry 19th Annual Meeting, Charlotte, NC. November 15-19.

Lipton, J., P.G. Welsh, and R. Playle. 1998. Cu Uptake Kinetics and Critical Gill Cu Concentrations in Chinook Salmon Fry. Society of Environmental Toxicology and Chemistry 19th Annual Meeting, Charlotte, NC. November 15-19.

Welsh, P.G., J. Lipton, and G. Chapman. 1998. Untested Assumptions in Water Effect Ratio Testing. Society of Environmental Toxicology and Chemistry 19th Annual Meeting, Charlotte, NC. November 15-19.

Barron, M.G., J. Lipton, and R. Ricker. 1997. Comparison of Injury Thresholds to Field Exposure Concentrations for a Weathered Petroleum. Society of Environmental Toxicology and Chemistry, San Francisco, CA.

Barron, M.G., E.E. Little, J. Lipton, and R.W. Ricker. 1997. Assessment of the Photoenhanced Toxicity of Petroleum. Arctic and Marine Oil Program, Vancouver, British Columbia, Canada.

Hudson, R., P. Welsh, T.L. Podrabsky, J. Lipton, D. Cacela, J. Marr, and C. Huang. 1997. Changes in DOC Concentration and Metal Bioavailability in Static Renewal Metal Toxicity Tests with Rainbow Trout — Implications for Interpreting Test Results. Society of Environmental Toxicology and Chemistry, San Francisco, CA.

Lipton. J. 1997. Injury Determination Approaches in Natural Resource Damage Assessment. American Society for Testing and Materials (ASTM), Symposium on Environmental Toxicology and Risk Assessment, ASTM Session, St. Louis, MO.

Lipton, J., D. Cacela, J.C.A. Marr, J.S. Meyer, and J. Hansen. 1997. Acute Toxicity of Organically Complexed Cu to Rainbow Trout. 24th Annual Aquatic Toxicity Workshop, Niagara Falls, Ontario.

Welsh, P.G., J. Lipton, T. Podrabsky, and R. Playle. 1997. Uptake Kinetics and Critical Gill-Cu Concentrations in Chinook Salmon Fry. 24th Annual Aquatic Toxicity Workshop, Niagara Falls, Ontario.

Welsh, P.G., J. Lipton, D. Cacela, T.L. Podrabsky, R. Hudson, J. Mastrine, C. Huang, and G. Chapman. 1997. Calcium Concentration v. Water Hardness: Modifiers of Metal Toxicity to Aquatic Organisms. Society of Environmental Toxicology and Chemistry, San Francisco, CA.

Anderson, M.J., M.G. Barron, S.A. Diamond, J. Lipton, and J.T. Zelikoff. 1996. Biomarker Selection for Restoration Monitoring of Fishery Resources. Environmental Toxicology and Risk Assessment: Modeling and Risk Assessment, Orlando, FL.

Cacela, D., K. LeJeune, and J. Lipton. 1996. Use of Multivariate Statistical Analysis to Delineate the Extent of Metals Contamination in a Floodplain. Annual Meeting of the Society of Environmental Toxicology and Chemistry, Washington, DC. November.

Galbraith, H., K. LeJeune, T. Podrabsky, and J. Lipton. 1996. Mass Mortality of Snow Geese in Southwest Montana due to Mining-Related Contaminants. Poster presentation at Society of Environmental Toxicology and Chemistry, Annual Meeting, Washington, DC. November.

LeJeune, K., D. Cacela, D. Lane, and J. Lipton. 1996. Ecological Impacts of Mine Waste Contaminated Alluvial Soils on Indigenous Riparian Communities. Annual Meeting of the Society of Environmental Toxicology and Chemistry, Washington, DC. November.

Lipton, J. 1996. What, No Cookbook?: Development of Ecological Risk Assessment Guidance. American Society for Testing and Materials (ASTM), Symposium on Environmental Toxicology and Risk Assessment. Orlando, FL. April.

Beltman, D., J. Lipton, D. Cacela, and W. Clements. 1995. Effects of Metals on a Montane Aquatic System Evaluated Using an Integrated Assessment Approach. Annual Meeting of the Society of Environmental Toxicology and Chemistry, Vancouver, British Columbia, Canada. November.

Hansen, J., H.L. Bergman, J.S. Meyer, R. MacRae, J. Marr, J. Lipton, and D. Cacela. 1995. The Avoidance of Copper by Salmonids as Affected by Metals Concentration, Organic Content, and Acclimation. Annual Meeting of the Society of Environmental Toxicology and Chemistry World Congress, Vancouver, British Columbia, Canada. November.

Lipton, J. 1995. Assessing Bioavailability, Lethality, and Sub-Lethal Growth Effects of Copper and Cobalt on Salmonids in a Rocky Mountain Stream. Invited Seminar: National Fisheries Contaminant Research Center, National Biological Service, Columbia, MO.

Lipton, J., J. Marr, and E.E. Little. 1995. Sub-Lethal Effects of Metals on Fish: Use as Endpoints in Natural Resource Damage Assessment. American Standards for Testing and Materials, 5th Symposium on Environmental Toxicology and Risk Assessment, Denver, CO.

Lipton, J., K. LeJeune, D. Cacela, H. Galbraith, and T. Podrabsky. 1995. Impacts of Smelter Emissions on Vegetation Communities: The Identification of Causal Mechanisms. Annual Meeting of the Society of Environmental Toxicology and Chemistry, Vancouver, British Columbia, Canada. November.

Lipton, J., J. Marr, D. Cacela, J. Hansen, and H.L. Bergman. 1995. Modeling Growth Responses of Rainbow Trout Fry as a Function of Tissue Copper Concentration and Copper Exposure Duration. Annual Meeting of the Society of Environmental Toxicology and Chemistry World Congress, Vancouver, British Columbia, Canada. November.

Lipton, J., J. Marr, J.S. Meyer, J. Hansen, R. MacRae, A. Maest, and H.L. Bergman. 1995. Acute Lethality and Bioavailability of Copper in the Presence of Dissolved Organic Carbon. Society of Environmental Toxicology and Chemistry World Congress, Copenhagen, Denmark. June.

MacRae, R., J.S. Meyer, J. Hansen, H.L. Bergman, A. Maest, J. Marr, D. Beltman, and J. Lipton. 1995. Determination of an Organic-Acid Analog of DOC for Use in Copper Toxicity Studies on Salmonids. Annual Meeting of the Society of Environmental Toxicology and Chemistry World Congress, Vancouver, British Columbia, Canada. November.

Maest, A., D. Beltman, and J. Lipton. 1995. Temporal Variability in Metal Concentrations in a Mine-Impacted Stream: Implications for Metal Bioavailability. Annual Meeting of the Society of Environmental Toxicology and Chemistry World Congress, Vancouver, British Columbia, Canada. November.

Marr, J., J. Lipton, D. Cacela, T. Podrabsky, J. Hansen, and H.L. Bergman. 1995. Acute Lethality of Cobalt, Copper, and Cobalt/Copper Mixtures to Rainbow Trout Fry. Annual Meeting of the Society of Environmental Toxicology and Chemistry World Congress, Vancouver, British Columbia, Canada. November.

Marr, J., J. Lipton, A. Maest, D. Cacela, J.S. Meyer, J. Hansen, R. MacRae, and H.L. Bergman. 1995. Acute Lethality and Bioavailability of Copper in the Presence of Dissolved Organic Carbon. Annual Meeting of the Society of Environmental Toxicology and Chemistry World Congress, Vancouver, British Columbia, Canada. November.

Meyer, J.S., D. Beltman, A. Maest, J. Marr, J. Lipton, C. Cors, D. Cacela, and R. MacRae. 1995. Use of Geochemical and Toxicity Modeling to Predict Lethality of Copper in a Metals-Impacted Stream. Annual Meeting of the Society of Environmental Toxicology and Chemistry World Congress, Vancouver, British Columbia, Canada. November.

Cacela, D. and J. Lipton. 1994. Phytotoxicity of Metal/Metalloid Contaminated Soils: Correlation Analysis to Determine Causality. Annual Meeting of the Society of Environmental Toxicology and Chemistry, Denver, CO. November.

Galbraith, H., K. LeJeune, and J. Lipton. 1994. Contaminant Effects on Terrestrial Resources: Vegetation Community and Wildlife Habitat Evaluation. Annual Meeting of the Society of Environmental Toxicology and Chemistry, Denver, CO. November.

Galbraith, H., J. Lipton, and K. LeJeune. 1994. Effects of Mine Wastes on Riparian Soils, Vegetation, Wildlife Habitat. Annual Meeting of the Society of Environmental Toxicology and Chemistry, Denver, CO. November.

Kapustka, L., J. Lipton, and K. LeJeune. 1994. Phytotoxicity of Metals and Arsenic-Contaminated Soils. Annual Meeting of the Society of Environmental Toxicology and Chemistry, Denver, CO. November.

LeJeune, K., J. Lipton, and H. Galbraith. 1994. Contaminant Effects on Terrestrial Resources: Sampling Design and Patterns of Soil Contamination. Annual Meeting of the Society of Environmental Toxicology and Chemistry, Denver, CO. November.

Lipton, J., J. Marr, and E.E. Little. 1994. Use of Behavioral Endpoints in Natural Resource Damage Assessment. Annual Meeting of the Society of Environmental Toxicology and Chemistry, Denver, CO. November.

Little, E.E., A.J. DeLonay, J. Lipton, and E. Smith. 1994. Behavioral Factors Influencing Spatial Distributions of Fish in Contaminated Environments. Annual Meeting of the Society of Environmental Toxicology and Chemistry, Denver, CO. November.

Marr, J.C.A., A.M. Farag, H.L. Bergman, and J. Lipton. 1994. The Effects of Metals Found in the Clark Fork River, Montana, on Rainbow (*Oncorhynchus mykiss*) and Brown Trout (*Salmo truta*). American Society for Testing and Materials (ASTM), 4th Symposium on Environmental Toxicology and Risk Assessment, Montreal, Quebec, Canada.

Galbraith, H. and J. Lipton. 1992. Terrestrial Ecological Risk Assessment: Links between Phytotoxicity and Wildlife Habitat. Annual Meeting of the Society of Environmental Toxicology and Chemistry, Cincinnati, OH. November.

Lipton, J. 1992. Assessment and Valuation of Ecosystem Perturbation: A Comparison of Methods. Society for Risk Analysis, San Diego, CA. December.

Lipton, J. 1992. Natural Resource Damage Assessment and Ecological Risk Assessment: What Falls through the Cracks? Annual Meeting of the Society for Risk Analysis, San Diego, CA. December.

Lipton, J. and H. Galbraith. 1992. Natural Resource Damage Assessment and Ecological Risk Assessment: A Comparison. Annual Meeting of the Society of Environmental Toxicology and Chemistry, Cincinnati, OH. November.

Lipton, J. and H. Galbraith. 1992. Treatment of Uncertainty in Ecological Risk Assessment: Be Careful What You Wish For. Invited presentation at "Water Quality Standards for the

21st Century." U.S. Environmental Protection Agency sponsored conference, Las Vegas, NV. September.

Lipton, J., H. Galbraith, D. Wartenburg, and J. Burger. 1991. A Paradigm for Ecological Risk Assessment. Annual Meeting of the Society of Environmental Toxicology and Chemistry, Seattle, WA.

Lipton, J. 1990. Modeling Uncertainties in Health Risks from Ocean Dumping. Annual Meeting of the Society of Environmental Toxicology and Chemistry.

Lipton, J. 1990. Movement of Pollutants through a Marine Food-Web. Annual Meeting of the Natural Resources Modeling Association.

Lipton, J. 1989. Uncertainty in the Calculation of Human Health Risks Associated with the Consumption of Contaminated Seafood. Student Poster Award: Annual Meeting of the American Fisheries Society.

Lipton, J. 1986. Trading Plaices: Bilateral Trade and Management Implications of the Georges Bank Boundary Delimitation, Resource Economies in Emerging Free Trade, University of Maine. January.

Professional Affiliations

- Editorial Board, Science of the Total Environment (1999-2003)
- Editorial Board, *Environmental Toxicology and Chemistry* (1994-1996)
- Member, Society of Environmental Toxicology and Chemistry
- Member, American Fisheries Society
- Expert Peer Review Panel on Ecological Risk Assessment, Department of Energy (DOE), Center for Risk Excellence.

Testimony

- State of Montana v. Atlantic Richfield Company, No. CV-83-317-HLN-PGH, United States District Court for the District of Montana, Helena Division.

- United States of America v. Asarco Incorporated et al., No. CV-96-0122-N-EJL, United State District Court for the District of Idaho.

- United States v. The New Portland Meadows, Inc., et al. No. CV-3-00-00507-KI, United States District Court of the District of Oregon.

Greg Koonce, CFP

As the founding partner of Inter-Fluve, Mr. Koonce has worked on land and water resource restoration projects that focus on fish habitat since 1980. Greg specializes in the development of salmonid habitat designs that function within the altered characteristics and design constraints of urbanized stream systems. He has conducted research into various life stage habitat requirements for trout, Steelhead, and Pacific salmon. He has developed strategies to remedy migratory passage problems for both adult and juvenile salmonids. Greg combines his fisheries background with several years of work in fluvial geomorphology involving studies in stream channel form and process including storm event related scour and deposition characteristics of natural channels and sediment transport dynamics. Greg frequently provides fisheries habitat and channel restoration expertise to large urban planning efforts involving aquatic resources. Greg's communication skills and knowledge of fisheries issues are commonly used to facilitate the interaction between agencies, municipalities, and citizen groups concerned with riparian areas, greenways, and stream habitats. He has served in advisory positions on several large-scale riparian restoration projects including one within a World Heritage Site in California. He has also served in a technical advisory role to Bonneville Power Administration (BPA) assisting in their efforts to develop criteria for salmonid recovery in Oregon, Washington, Idaho, and Montana.

Selected Project Experience

Cedar River Fish Passage Improvement Project – Seattle, WA. Finalized negotiations for mitigation requirements to offset habitat losses incurred as a result of upgraded water supply facilities for the City of Seattle. Managed the development of a habitat mitigation plan, oversaw the construction and implementation of habitat mitigation elements and wrote a habitat mitigation monitoring plan. Project is unique due to the accelerated time frame (final mitigation agreement to construction completion in less than a year) and the establishment of habitat improvements for use by juvenile salmonids during winter storm events.

San Antonio River Improvements – San Antonio, TX. Currently providing fisheries habitat and geomorphic review for the planned recovery of habitats within a 13-mile reach of a highly modified urban river. Habitat recovery for fish and native riparian habitats is especially challenging due to the overriding goals for flood abatement and infrastructure protection. Emphasis is placed on restoration of fundamental ecosystem processes that result from geomorphic and hydraulic processes altered through the impact of urban influences on geology and flow regime.

PRINCIPAL / FISHERIES BIOLOGIST

EXPERTISE

Fish Habitat as a product of Stream Geomorphology

Fish Biology Interactions with Fluid Dynamics

Fisheries Habitat Rehabilitation Design

Fish Population Assessments

Fish Habitat Assessments

PROFESSIONAL AFFILIATIONS AND REGISTRATIONS

Certified Fisheries Professional
American Fisheries Society

Oregon Trout

EDUCATION

Graduate level work in Watershed Management, Humboldt State University

BS, Fisheries Biology, Humboldt State University, 1980

Greg Koonce: Other Significant Projects

37 Mile Creek Channel Extension – Haines, AK. Provided design criteria for the design and subsequent monitoring of a 7,000-foot extension of the lower end of 37 Mile Creek, a tributary to the Klehini River. Greg was lead designer for the project's 20 acres of emergent wetlands. Instrumental to his design concept was the inclusion of streams within the wetlands for greater fish habitat enhancement. Criteria included habitat preferences for all species of Eastern Pacific salmon, Dolly Varden and Coastal Cutthroat including both adult and juvenile life stages. Habitat preferences were given to Coho and Chum salmon with special considerations for spawning and rearing of these fish in clear water tributaries of glacial river systems.

Fish Creek Channel and Fish Habitat Assessment – Mt. Hood National Forest, OR. Conducted flood damage assessment of fisheries habitat within an at-risk habitat for Steelhead, Coho and Chinook salmon on the Mt. Hood National Forest. Pre- and post-flood fisheries habitat typing data was statistically manipulated to determine the impact of a flood estimated to have exceeded the 100-year recurrent flow. Habitat constituents were compared with both historical air photos and post-flood longitudinal and cross-sectional surveys to develop insight into possible geomorphic-based response patterns. Management recommendations were developed to assist USFS personnel in developing restoration plans for the basin.

Storm Drainage Master Plan for Rock, Bronson, and Willow Creeks – Portland, OR. Developed stream channel restoration designs within three highly urbanized drainages of the Portland metropolitan area. Special consideration was given to habitat and biological requirements of indigenous Cutthroat trout populations, duration/frequency of discharge events, sediment management, and relative levels of urban impact.

Howard Hanson Dam Additional Water Storage Project – Tacoma, WA. Played a key role in the development of draft mitigation and restoration designs for the Green River and area tributaries following the authority of the Army Corps of Engineers and the City of Tacoma. Subsequently, served as a major author for work plans and design goals for 19 fish habitat improvement projects. Currently under a continuing contract with the Seattle District Army Corps of Engineers to assist in the development of design plans for these projects.

Rio Chimehuin and Rio Quilquihue Fish Habitat Improvements – Provincia de Neuquen, Patagonia, Argentina. Provided plans for the improvement of trout habitat on two major Argentine rivers and developed preliminary designs for the creation of three kilometers of spring creek. This project is located within the boundaries of a well-established resort catering to European and North American fly fishers.

Hardy Creek Salmon Habitat Restoration – Skamania, WA. Developed restoration designs for a significant salmonid spawning and rearing stream within a Federal Wildlife Refuge along the Columbia River. Flood flows severely damaged important spawning habitat for lower river Coho and Chum salmon and significantly impaired their movement through a concrete arch culvert. Design criteria were formulated and, with the assistance of US Fish and Wildlife personnel, developed to restore the channel to pre-flood habitat conditions and to facilitate the movement of all life stages through the culvert. Construction was conducted with Federal refuge workers and equipment. In-stream channel work was completed in the late summer of 1996 with successful Coho and Chum spawning observed in both the fall of 1996 and 1997. Juvenile migrations continue to be a monitored annually by the refuge personnel.

Greg Koonce: Other Significant Projects, continued

Picnic Point Creek Flood Damage Repair and Channel Enhancement – Snohomish County, WA. Developed fish passage and rearing habitat criteria for a flood damaged stream in suburban Everett. The wet winter of 1996 caused a portion of a county highway to fail and slide into a significant Steelhead, Coho and Chum salmon spawning stream. Emergency road crews were mobilized to repair the highway and mitigate for the in-stream damages. The habitat enhancement and channel repair designs were developed within an extremely aggressive schedule, and supervision was provided by Inter-Fluve throughout all in-stream construction activities.

Nooksack River Monitoring Plan – Bellingham, Washington. Assisted in the development of a monitoring strategy for a large-scale riverbank protection project on the Nooksack River in North-western Washington. This project involved every major species of anadromous salmonid in the Northeastern Pacific and some non-migratory species as well. A fisheries habitat monitoring method based on life-stage preferences and measurements and supplemented with visual estimates of physical conditions was developed for rapid assessment of habitat. The method places emphasis on measurements during specific hydrologic/hydraulic conditions of various seasonal uses by adults and juveniles.

Sucker Creek Mitigation, WA. Assisted in the development of a mitigation strategy for the loss of three miles of anadromous fishery stream and 10 acres of emergent wetland during the construction of a regional landfill in western Washington. Developed design plans for three miles of relocated stream, three off channel rearing ponds for Cutthroat trout and Coho salmon, and assisted with designs for 10 acres of emergent wetland. Provided construction oversight for construction of the mitigation measures.

Cove East/Upper Truckee River & Wetland Restoration Project, CA. Assisted with the development of several conceptual level river restoration designs for a degraded river system at Lake Tahoe. A fundamental goal of this project was to restore water quality and ecological function to the river, its surrounding floodplain and attendant wetlands. Dominant discharge parameters were refined and applied to the topography of the project site in a manner that maintained slope, continuity of discharge, sediment transport capacity and sediment transport competence. Each design concept was evaluated and ranked according to the following criteria: short-term maintenance, design effort and cost, permitting, water quality impacts, flooding impacts, long-term maintenance, construction difficulty, channel stability, biological resources, and water quality benefits.

Greg Koonce: Publications/Workshops

Koonce, G. P., 2003. Invited Panel Member, USFS Fish Passage Workshop. Vancouver, Washington.

Koonce, G. P., 2002. A Discussion on Stream Restoration/Enhancement Design Approaches and the Need for Standards. Columbia River Basin Conference. Spokane, Washington.

Koonce, G. P., 2001. Bioengineering Techniques and Design Criteria for the Repair of Stream Bank Failures. Workshop for Oregon Department of Transportation. Salem, Oregon.

Koonce, G. P., 2001. Applications of Bioengineering Techniques for Improving Stability of Stream Banks. Workshop for City of Eugene Department of Public Works. Eugene, Oregon.

Koonce, G.P., 2000. Applications of Fluvial Geomorphology in Stream Habitat Restoration Design. USDA Region 6 Stream and Watershed Restoration Design and Implementation Workshop. USDA Forest Service, Pendleton, OR.

Greg Koonce: Publications/Workshops, continued

Koonce, G.P., 2000. Reconstruction of a Flood Impacted Stream on the Pierce Wildlife Refuge. Wolftree, Stream and Watershed Restoration Workshop. Stevenson WA.

Koonce, G. P., 1999. Bioengineering Techniques and Design Criteria for Stabilization of Major River Bank Failures. Workshop for Portland Development Commission. Portland, OR.

Koonce, G. P., 1999. Re-Constructing Wetland Habitats, Issues and Thoughts. Lecture at the monthly meeting of the Columbia Gorge Chapter of the Oregon Native Plants Society.

Koonce, G. P., 1998. Aquatic Resource Enhancement: An Approach to the Design, Construction and Rehabilitation of Streams. Workshop for the Allied Architectural and Arts School. University of Oregon, Eugene, OR.

Koonce, G. P., 1998. Stream Condition and Rehabilitation Efforts. Sediment Workshop. Oregon Department of Environmental Quality. Portland, OR.

Koonce, G. P., 1998. Streams and Watersheds, Establishing Design Criteria for Rehabilitation. Workshop for Development of Integrated Streambank Protection Guidelines. Washington Department of Fish and Wildlife, Washington Department of Ecology. Ellensburg, WA.

Koonce, G. P., 1998. Impact of Glacial and Anthropogenic Sediments on Fish and Their Habitat. Hood River Watershed Meeting. Hood River, OR.

Mayer-Reed, C. and G. Koonce, 1998. Concepts and Technology of the A-mazing Water Garden. Annual Meeting of the American Society of Landscape Architects. Portland, OR.

Koonce, G. P., 1998. Multi-disciplinary Science and its Application in Riparian Rehabilitation. Lecture. Mt. Hood Community College. Gresham, OR.

Koonce, G. P., 1998. Stream Channel Boundary Protection; Appropriate Levels for Urban and Natural Systems. Lecture for the School of Allied Architectural and Arts. University of Oregon, Eugene, OR.

Koonce, G. P., 1997. Using Bioengineering Methods to Repair Stream Bank Failures. Workshop for Development of Integrated Streambank Protection Guidelines. Washington Department of Fish and Wildlife. Vancouver, WA.

Koonce, G.P., 1997. Applications of Fluvial Geomorphology in Stream Habitat Restoration Design. USDA Region 6 Stream and Watershed Restoration Design and Implementation Workshop. USDA Forest Service, Trout Lake, WA.

Koonce, G.P., 1997. Using Trout Habitat Assessment Data for Restoration of Stream Habitat. Design of Natural Stream Channels. Inter-Fluve, Inc. Bozeman, MT.

Koonce, G.P., 1997. Concept and Approach to Biotechnical Stream Channel Restoration Techniques. Integrated Bank Protection Seminar, Washington Department of Fish and Wildlife, Region 5, Vancouver, WA.

Koonce, G.P. 1997. Strategies for Fish Habitat Restoration Following Large Magnitude Flood Events. Mt. Hood National Forest Flood Symposium. USFS, Sandy, OR.

Greg Koonce: Publications/Workshops, continued

Koonce, G.P. 1996. Applications of Fluvial Geomorphology in Stream Habitat Restoration Design. USDA Region 6 Workshop on Stream Channel Restoration. USDA Forest Service, Cascade Locks, OR.

Koonce, G.P. 1996. Using Trout Habitat Assessment Data for Restoration of Stream Habitat. Applied Fluvial Geomorphology in Stream Habitat Design and Restoration. Wetlands Training Institute. Bozeman, MT.

Koonce, G.P. 1996. Effects and Implications of Urban Hydrology on Stream Habitat. Integrating Stormwater into the Urban Fabric. Annual Meeting of the Oregon Chapter of the American Society of Landscape Architects. Portland, OR.

Koonce, G.P. 1995. Applications of Fluvial Geomorphology in Stream Restoration Design. A Workshop on Stream Channel Restoration. USFS, Trout Lake, WA.

Koonce, G.P. 1995. Analog Method for in-Channel Restoration. Stream Restoration Conference. British Columbia Ministry of Fisheries, Squamish, Canada.

Challanger, G.E., J. Baumert, S. R. Haak, and G. P. Koonce. 1994. Mitigation for Aquatic Resource Losses: Creation of Diversion Stream Channels, Wetlands and Off-Channel Ponds. Society of Wetland Scientists, 15th Annual Meeting. Portland, OR.

Koonce, G.P. 1993. Trout Spawning Habitat Mitigation: A Constructed Example. American Society of Civil Engineers. Conference on Water Resource Planning and Management. Seattle, WA.

Koonce, G.P. 1993. BioEngineered Solutions for Streambank Erosion. Proceedings of the American Society of Landscape Architects Annual Meeting. Chicago, IL.

Koonce, G.P. 1992. Urban Stream Erosion Control Methods. Symposium on Design of Storm Water Quality Management Practices. University of Wisconsin-Madison Department of Engineering Professional Development. Portland, OR.

Koonce, G.P. 1992. Training Session on Applying Basic Hydraulic Information to design of Trout Habitat Restoration Projects. American Fisheries Society Annual Meeting. Bozeman, MT.

Koonce, G.P. 1991. Using Basic Hydraulic Analysis for In-Channel Design. In: California Salmonid Stream Habitat Restoration Manual. CDF&G Inland Fisheries Division. Sacramento, CA.

Koonce, G.P. 1991. Urban Riparian Management. Symposium on Urban Riparian Issues. Utah State University. Logan, UT.

Koonce, G.P. 1990. Two-Pin Method for Design of Stream Habitat Enhancement. Proc. of the Humboldt Chapter of the Amer. Fish. Soc. Eureka, CA.

Gebhardt, K. A., and G. P. Koonce, et al, 1988. Creating Wildlife and Wetland Amenities in an Urban Environment. Symp. Proc. of the Rocky Mt. Chap. of the Soc. of Wetland Sci. Denver, CO.

Koonce, G.P. 1984. Channel Bedform Manipulation; An Alternative to Traditional Structure Oriented Stream Enhancement Methods. Proc. of the Colo-Wyo Chapter. of the Amer. Fish. Soc. Fort Collins, CO.

Greg Koonce: Awards

Educational Achievement Award for Instruction in Designing Stormwater Quality Management Practices, University of Wisconsin-Madison College of Engineering. 1992

Additional Education

40 – Hour OSHA Hazardous Waste Operations Training, 2003

Curriculum Vitae

Frank J. Rahel
Department of Zoology and Physiology
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Laramie, WY 82071
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Education`

University of Wisconsin, Madison, WI, 1982, PhD, Zoology
University of Wisconsin, Madison, WI, 1977, MS, Zoology
Kenyon College, Gambier, OH, 1974, BA, Biology

Professional Experience

Professor, Department of Zoology and Physiology, University of Wyoming, July 1998-present
Associate Professor, Department of Zoology and Physiology, University of Wyoming, July 1991-June 1998
Assistant Professor, Department of Zoology and Physiology, University of Wyoming, June 1985-June 1991
Postdoctoral Research Fellow, Department of Zoology and Ohio Cooperative Fishery Research Unit, Ohio State University, July 1983-May 1985
Postdoctoral Research Associate, Center for Limnology, University of Wisconsin-Madison, February 1982-June 1983

Research Interests

Fisheries biology, community ecology, fish-habitat relations, human impacts on aquatic environments

Courses taught

Fisheries management, ichthyology, general ecology, conservation biology, community ecology, ecological experiments

Professional activities

American Fisheries Society (life member, President of CO-WY Chapter, 1993)
Ecological Society of America (life member)
Society for Conservation Biology (member)
Associate editor, Transactions of the American Fisheries Society 1989-1991
Editor, Ecological Applications, 2001-2004

Awards and Honors

2003 Advisor and co-author for best student paper by Seth White. Joint meeting of the CO-WY and Bonneville chapters of the American Fisheries Society, Grand Junction, CO.
2002 Advisor and co-author for best student paper by Amy Schrank, Annual meeting of the CO-WY Chapter of the American Fisheries Society, Laramie, WY.
2001 Award of Excellence in Fisheries Education from the American Fisheries Society.
2001 Advisor and co-author for best student paper by Amy Schrank, Annual meeting of the CO-WY Chapter of the American Fisheries Society, Cheyenne, WY.
2000 Advisor and co-author for best student paper by Amy Schrank, Annual meeting of Western Division of the American Fisheries Society, Telluride, CO.
2000 John P. Ellbogen Meritorious Classroom Teaching Award, Campus-wide teaching award of the University of Wyoming.
2000. Co-advisor (with Wayne Hubert) for Outstanding Dissertation in the Biological Sciences, University of Wyoming (Dissertation of Carter Kruse).
1999 Advisor and co-author for best student paper by Doug Novinger, Annual meeting of CO-WY Chapter of the American Fisheries Society, Cheyenne, WY.
1998. Advisor and co-author, best student paper by Doug Novinger and Nate Nibbelink, Meeting of CO-WY Chapter of the American Fisheries Society, Grand Junction, CO.
1996 Best paper published in Transactions of the American Fisheries Society.
1993 Best paper – Annual meeting of the CO-WY Chapter of the American Fisheries Society, Laramie, WY.
1992 Advisor and co-author for best student paper by James De Staso, National meeting of the American Fisheries Society, Rapid City SD.

Refereed Publications

Schrank, A.J. and F.J. Rahel. In press. Movement patterns in inland cutthroat trout: management and conservation implications. Canadian Journal of Fisheries and Aquatic Sciences.

Quist, M., W.A. Hubert, and F.J. Rahel. In press. Elevation and stream-size thresholds affect distribution of native and exotic warmwater fishes in Wyoming. Journal of Freshwater Ecology.

Quist, M., W.A. Hubert, and F.J. Rahel. In press. Fish assemblage structure following impoundment of a Great Plains river. Western North American Naturalist.

Rahel, F.J. 2004. Unauthorized fish introductions: fisheries management of the people, for the people, or by the people? Propagated Fishes in Resource Management, Proceedings of a Symposium by the American Fisheries Society.

Quist, M., W.A. Hubert, and F.J. Rahel. 2004. Relations among habitat characteristics, exotic species, and turbid-river cyprinids in the Missouri River drainage of Wyoming. Transactions of the American Fisheries Society 133:727-742.

Quist, M., W.A. Hubert, and F.J. Rahel. 2003. Exotic piscivorous fishes and reduced intermittence affect suckermouth minnows in a southeastern Wyoming stream. Intermountain Journal of Sciences 9:62-65.

Novinger, D.L. and F.J. Rahel. 2003. Is isolating cutthroat trout above artificial barriers in small headwater streams an effective long-term conservation strategy? Conservation Biology 17:772-781.

Johnstone, H.C. and F.J. Rahel. 2003. Assessing temperature tolerance of cutthroat trout based on constant and cycling thermal regimes. Transactions of the American Fisheries Society 132:92-99.

Schrank, A.J., F.J. Rahel, and H.C. Johnstone. 2003. Evaluating laboratory-derived thermal criteria in the field: an example involving cutthroat trout. Transactions of the American Fisheries Society 132:100-109.

Rahel, F.J. 2002. Homogenization of freshwater faunas. Annual Review of Ecology and Systematics Volume 33:291-315. (Invited article).

Kruse, C.G., W.A. Hubert, F.J. Rahel. 2001. An assessment of headwater isolation as a conservation strategy for cutthroat populations in the Absaroka Mountains of Wyoming. Northwest Science 75:1-11.

Rahel, F.J. 2000. Homogenization of fish faunas across the United States. 2000. Science 288:854-856.

Kruse, C.G., W.A. Hubert, and F.J. Rahel. 2000. Status of Yellowstone cutthroat trout in Wyoming waters. North American Journal of Fisheries Management 20:693-705.

Patton, T.M., W.A. Hubert, F.J. Rahel, and K.G. Gerow. 2000. Evaluation of one-pass electrofishing and seining for estimating species richness in Great Plains streams. North American Journal of Fisheries Management 20:394-398.

Rahel, F.J. and N.P. Nibbelink. 1999. Spatial patterns in relations among brown trout distribution, summer air temperature, and stream size in Rocky Mountain streams. Canadian Journal of Fisheries and Aquatic Sciences 56(Supplement 1):43-51.

Patton, T.M., W.A. Hubert, and F.J. Rahel. 1998. Ichthyofauna in streams of the Missouri River drainage, Wyoming. The Prairie Naturalist 30:9-21.

Taniguchi, Y., F.J. Rahel, D.C. Novinger, and K.G. Gerow. 1998. Temperature mediation of competitive interactions among three fish species that replace each other along longitudinal stream gradients. Canadian Journal of Fisheries and Aquatic Sciences 55:1894-1901.

Patton, T.M., F.J. Rahel, and W.A. Hubert. 1998. Using historical data to assess changes in Wyoming's fish fauna. Conservation Biology 12:1120-1129.

Thompson, P.D. and F.J. Rahel. 1998. Evaluation of human-made barriers in small Rocky Mountain streams in preventing upstream movement of brook trout. North American Journal of Fisheries Management 18:206-210.

Kruse, C.G., W.A. Hubert, and F.J. Rahel. 1998. Single-pass electrofishing predicts trout abundance in mountain streams with sparse habitat. North American Journal of Fisheries Management 18:940-946.

Rahel, F.J. 1997. From Johnny Appleseed to Dr. Frankenstein: changing values and the legacy of fisheries management. Fisheries 22(8):8-9.

Kruse, C.G., W.A. Hubert, and F.J. Rahel. 1997. Geomorphic influences on the distribution of Yellowstone cutthroat trout in the Absaroka Mountains, Wyoming. Transactions of the American Fisheries Society 126:418-427.

Kruse, C.G., W.A. Hubert, and F.J. Rahel. 1997. Using otoliths and scales to describe age and growth of Yellowstone cutthroat trout in a high-elevation stream system, Wyoming. Northwest Science 71:30-38.

Rahel, F.J., C.J. Keleher, and J.L. Anderson. 1996. Potential habitat loss and population fragmentation for cold water fish in the North Platte River drainage of the Rocky Mountains: Response to climate warming. Limnology and Oceanography 41:1116-1123.

Thompson, P.D. and F.J. Rahel. 1996. Evaluation of depletion-removal electrofishing of brook trout in small Rocky Mountain streams. North American Journal of Fisheries Management 16:332-339.

Kruse, C.G., W.A. Hubert, and F.J. Rahel. 1996. Sources of variation in counts of meristic features of Yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri*). Great Basin Naturalist 56:300-307.

Keleher, C.J. and F.J. Rahel. 1996. Thermal limits to salmonid distributions in the Rocky Mountain region and potential habitat loss due to global warming: A Geographic Information System (GIS) approach. Transactions of the American Fisheries Society 125:1-13.

Rahel, F.J. and J.W. Nutzman. 1994. Foraging in a lethal environment: predation by fish on *Chaoborus* in the hypoxic zone of a stratified lake. Ecology 75:1246-1253.

De Staso, J. III and F.J. Rahel. 1994. Influence of water temperature on interactions between young Colorado River cutthroat trout and brook trout in a laboratory stream. Transactions of the American Fisheries Society 123:289-297.

Kolar, C.S. and F.J. Rahel. 1993. Interaction of a biotic factor (predator presence) and an abiotic factor (low oxygen) as an influence on benthic invertebrate communities. Oecologia 95:210-219.

Johnson, S.L., F.J. Rahel, and W.A. Hubert. 1992. Factors influencing the size structure of brook trout populations in Wyoming beaver ponds. North American Journal of Fisheries Management 12:118-124.

Bozek, M.A. and F.J. Rahel. 1992. Generality of microhabitat suitability models for young Colorado River cutthroat trout across sites and among years in Wyoming streams. Canadian Journal of Fisheries and Aquatic Sciences 49:552-564.

Rahel, F.J. and W.A. Hubert. 1991. Fish assemblages and habitat gradients in a Rocky Mountain-Great Plains stream: biotic zonation and additive patterns of community change. Transactions of the American Fisheries Society 120:319-332.

Bozek, M.A. and F.J. Rahel. 1991. Assessing habitat requirements of young Colorado River cutthroat trout by use of macrohabitat and microhabitat analysis. Transactions of the American Fisheries Society 120:571-581.

Bozek, M.A. and F.J. Rahel. 1991. Comparison of streamside visual counts to electrofishing estimates of Colorado River cutthroat trout fry and adults. North American Journal of Fisheries Management 11:38-42.

Rahel, F.J. 1990. The hierarchical nature of community persistence: a problem of scale. The American Naturalist 136:328-344.

Rahel, F.J. 1990. Anomalous temperature and oxygen gradients under the ice of a high plains lake in Wyoming, U.S.A. Limnology and Oceanography 35:447-451.

Rahel, F.J. and C.S. Kolar. 1990. Trade-offs in the response of mayflies to low oxygen and fish predation. Oecologia 84:39-44.

Winkle, P.L., W.A. Hubert, and F.J. Rahel. 1990. Relations between brook trout standing stocks and habitat features in beaver ponds in southeastern Wyoming. North American Journal of Fisheries Management 10:72-79.

Rahel, F.J. 1989. Nest defense and aggressive interactions between small benthic fish and crayfish. Environmental Biology of Fishes 24:301-306.

Rahel, F.J. 1989. Simulation of vertical limnological gradients. Journal Freshwater Ecology 5:247-252.

Hubert, W.A. and F.J. Rahel. 1989. Relations of physical habitat to abundance of four nongame fishes in high plains streams: a test of Habitat Suitability Index models. North American Journal of Fisheries Management 9:332-340.

Magnuson, J.J., C.A. Paszkowski, F.J. Rahel, and W.M. Tonn. 1989. Fish ecology in severe environments in northern Wisconsin. Pages 487-515 *in* R.R. Sharitz and J.W. Gibbons (eds.) Freshwater Wetlands and Wildlife. DOE-CONF 8603101. Office of Scientific and Technical Information. U.S. Dept. Energy, Oak Ridge, TN.

Rahel, F.J. and R.A. Stein. 1988. Complex predator-prey interactions and predator intimidation among crayfish, piscivorous fish, and small benthic fishes. Oecologia 75:94-98.

Rahel, F.J. 1986. Biogeographic influences on fish species composition of northern Wisconsin lakes with applications for lake acidification studies. Canadian Journal of Fisheries and Aquatic Sciences 43:124-134.

Rahel, F.J., J.D. Lyons and P.A. Cochran. 1984. Stochastic or deterministic regulation of assemblage structure. It may depend on how the assemblage is defined. The American Naturalist 124:583-589.

Rahel, F.J. 1984. Factors structuring fish assemblages along a bog lake successional gradient. Ecology 65:1276-1289.

Magnuson, J.J. J.P. Baker, and F.J. Rahel. 1984. A critical assessment of effects of acidification on fisheries in North America. Philosophical Transactions of the Royal Society of London. B305:5010516.

Rahel, F.J. 1983. Population differences in acid tolerance between yellow perch *Perca flavescens* from naturally acidic and alkaline lakes. Canadian Journal of Zoology 61:147-152.

Rahel, F.J. and J.J. Magnuson. 1983. Low pH and the absence of fish species in naturally acidic lakes: inferences for cultural acidification. Canadian Journal of Fisheries and Aquatic Sciences 40:3-9.

Rahel, F.J. 1981. Selection for zinc tolerance in fish: results from laboratory and wild populations. Transactions of the American Fisheries Society 110:19-28.

Books and Book Chapters

Fisher, W.L. and F.J. Rahel. Editors. 2004. Geographic information systems in fisheries. American Fisheries Society, Bethesda, MD.

Rahel, F.J. 2004. Introduction to GIS in fisheries. Pages 1-12 *in* W.L. Fisher and F.J. Rahel, editors. Geographic information systems in fisheries. American Fisheries Society, Bethesda, MD.

Fisher, W.L. and Rahel F.J. 2004. Geographic information systems applications in stream and river fisheries. Pages 49-84 *in* W.L. Fisher and F.J. Rahel, editors. Geographic information systems in fisheries. American Fisheries Society, Bethesda, MD.

Rahel, F.J. and D.A. Jackson. Watershed-level approaches. Book chapter *In* C. Guy and M. Brown, editors. Analysis and Interpretation of Freshwater Fisheries Data. American Fisheries Society, Bethesda, MD. In preparation.

Rahel, F.J. 2002. Using current biogeographic limits to predict fish distributions following climate change. Pages 99-110 *in* N. McGinn , editor. Fisheries in a Changing Climate. American Fisheries Society Symposium 32:99-110. Bethesda, MD.

N. L. Poff, P.L. Angermeier, S.D Cooper, P.S. Lake, K.D. Fausch, K.O. Winemiller, L.A.K. Mertes, M.W. Oswood, J. Reynolds, and F.J. Rahel. 2001. Fish diversity in streams and rivers. Pages 315-349 *in* Chapin, F.S., III, O.E. Sala, and E. Huber-Sannwald, eds. Global biodiversity in a changing environment: scenarios for the 21st century. Springer-Verlag, NY.

Rahel, F.J., R.T. Muth, and C.A. Carlson. 1999. Endangered Species Management. Chapter 15 *in* C.C. Kohler and W.A. Hubert, editors. Inland Fisheries Management in North America. American Fisheries Society, Bethesda, MD.

Other Publications

Rahel, F.J. and L.A. Thel. In preparation. Plains topminnow (*Fundulus sciadicus*): a technical conservation assessment. [Online}. USDA Forest Service, Rocky Mountain region.

Rahel, F.J. and L.A. Thel. 2004. Sturgeon chub (*Macrhybopsis gelida*): a technical conservation assessment. [Online}. USDA Forest Service, Rocky Mountain region. Available at http://www.fs.fed.us/r2/projects/scp/assessments/sturgeonchub.pdf

Rahel, F.J. and L.A. Thel. 2004. Flathead chub (*Platygobio gracilis*): a technical conservation assessment. [Online}. USDA Forest Service, Rocky Mountain region. Available at http://www.fs.fed.us/r2/projects/scp/assessments/flatheadchub.pdf

Rahel, F.J. and L.A. Thel. 2004. Plains killifish (*Fundulus zebrinus*): a technical conservation assessment. [Online}. USDA Forest Service, Rocky Mountain region. Available at http://www.fs.fed.us/r2/projects/scp/assessments/plainskillifish.pdf

Covich, A.P., M.A. Baker, R. Behneke, D.W. Blinn, L.M. Carter, J. Chambers, T.A. Crowl, J.P. Dobrowolski, C.P. Hawkins, C. Luecke, J. Miller, N.L. Poff, F.J. Rahel, J.C. Schmidt, S.

Selby, A.L. Sheldon, M. Vinson, F.H. Wagner. 2003. Natural Ecosystems II. Aquatic Ecosystems. Pp. 185-206 *in* F.H. Wagner (ed). Rocky Mountain/Great Basin Regional Climate Change Assessment. Report for the U.S. Global Change Research Program. Utah State University, Logan, UT. 240 pp.

Winters D., B. Bohn, D. Cooper, G. Eaglin, J. Hamerlinck, C. Hirsch, N.L Poff, C. Quimby, F.J. Rahel, P. Rau, D. Scaife, D. Staley, M. Welker and E. Wohl. 2003. Conceptual framework and protocols for conducting broad scale aquatic, riparian, and wetland ecological assessments. Document developed for the U.S.D.A. Forest Service Region 2, Denver, CO.

Rahel, F.J. 2000. Book Review of "Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities" by Thomas P. Simon (ed). Transactions of the American Fisheries Society. 129:886-887.

Irwin, E.R., F.J. Rahel, D.L. Parrish, and D.H. Wahl. 1998. Enhancing professionalism: awards and grants for student members of the American Fisheries Society. Fisheries 23(8):20-23.

Patton, T.M., C.A. Wheeler, W.A. Hubert, and F.J. Rahel. 1996. A survey of the warmwater stream fishes of the Platte River drainage in Wyoming. Pages 2-12 *in* Proceeding of the Platte River Basin Ecosystem Symposium, Kearney, NE. University of Nebraska Cooperative Extension-Platte Watershed Program. Lincoln, NE.

Rahel, F.J. 1991. Guidelines for determining when special fishing regulations are likely to improve salmonid fisheries. Project Report to Wyoming Game and Fish Department, Cheyenne, WY.

Rahel, F.J. 1985. Biogeographic influences, species interactions, and lake acidification. Pages 30-41 *in* P.J. Rago and R.K. Schreiber (eds.) Acid Rain and Fisheries: A Debate of the Issues. U.S. Fish and Wildlife Service. Biological Report 80(40.21).

Magnuson, J.J., F.J. Rahel, J.P. Baker, R. Singer, J.H. Peverly and C.T. Driscoll. 1984. Conclusions: Effects of acidic deposition on aquatic biota. Pages 5-149 to 5-159 *in* R.A. Linthurst (ed.) The acidic deposition phenomenon and its effects. U.S. Environmental Protection Agency. EPA-600/8-83-016BF.

Rahel, F.J. 1984. Biota of naturally acidic waters. Pages 5-3 to 5-14 *in* R.A. Linthurst (ed.) The acidic deposition phenomenon and its effects. U.S. Environmental Protection Agency. EPA-600/8-83-016BF.

Rahel, F.J. 1984. Book Review of "Acid Rain/Fisheries" by Raymond E. Johnson (ed). Transactions of the American Fisheries Society, 113:95-96.

Rahel, F.J. and J.J. Magnuson. 1981. Fish communities in naturally acidic lakes: examination of genetic adaptation to low pH. Pages 334-335 *in* D. Drablos and A. Tollan, (eds.) Proc. International Conference on the Ecological Effects of Acid Precipitation. Sandefjord, Norway, March 1981. SNSF-Project.

Magnuson, J.J., F.J. Rahel, M.J. Talbot, A.M. Forbes and P.A. Medvick. 1980. Ecological studies of fish influenced by a power plant. U.S. Environmental Protection Agency, Ecological Research Series. EPA-600.3-8-078.

Meeting presentations (since 1990)

Biogeographic barriers, connectivity, and homogenization of freshwater fish faunas: it's a small world after all. F.J. Rahel. Invited paper for the 2nd International Symposium on Riverine Landscapes. Bredsel, Alvsbyn, Sweden. August, 2004.

The impact of irrigation canals on Bonneville cutthroat trout populations and movement patterns in the Smiths Fork drainage, western Wyoming. J.J. Roberts and F.J. Rahel. Western Division of the American Fisheries Society meeting, Salt Lake City, Utah, March 2004.

Native large-river fishes in isolated tributary streams: factors affecting roundtail chub, flannelmouth sucker, and bluehead sucker in the Upper Muddy Creek Watershed, Wyoming. M.R. Bower, W.A. Hubert, and F.J. Rahel. Western Division of the American Fisheries Society meeting, Salt Lake City, Utah, March 2004.

Warmwater stream assessment in Wyoming: a process-driven approach. Quist, M.C., W.A. Hubert, and F.J. Rahel. Southern Division of the American Fisheries Society meeting, Oklahoma City, Oklahoma, February 2004.

A process-driven approach for assessing warmwater streams in Wyoming. Quist, M.C., W.A. Hubert, and F.J. Rahel. Western Division of the American Fisheries Society meeting, Salt Lake City, Utah, March 2004. Poster

Unauthorized fish introductions: fisheries management of the people, for the people, or by the people? F.J. Rahel. Invited presentation at the Propagated Fish in Resource Management Symposium sponsored by the American Fisheries Society. Boise, ID. June 2003.

Mitigating the mismatch in how the public and ecologists view species introductions. F.J. Rahel. Conference on Bioinvasions. University of Wyoming, Laramie, WY June 2003.

History, beaver dams, and spatial heterogeneity of young-of-year cutthroat trout. S.M. White and F.J. Rahel. Invited paper for symposium: "Understanding wild riverine fish populations at watershed to regional scales: new concepts, tools and applications." Invited presentation. American Fisheries Society meeting. Quebec City, Quebec, August 2003.

Can patterns of spatial correlation determine scales at which environmental variables influence fish density? Nathan P. Nibbelink and Frank J. Rahel. Invited paper for symposium: Understanding wild riverine fish populations at watershed to regional scales: new concepts, tools, and applications. American Fisheries Society, Quebec City, Quebec, August 2003.

.Effect of impoundments on habitat characteristics, exotic piscivores, and turbid-river cyprinids in Wyoming. Quist, M.C., W.A. Hubert, and F.J. Rahel. American Fisheries Society meeting. Quebec City, Quebec, August 2003.

A process-driven approach for assessing warmwater streams in Wyoming. Quist, M.C., W.A. Hubert, and F.J. Rahel. American Fisheries Society meeting. Quebec City, Quebec, August 2003. (poster).

Effect of impoundments on physicochemical habitat and turbid-river cyprinids in the Missouri River drainage of Wyoming. Quist, M.C., W.A. Hubert, and F.J. Rahel. Joint meeting of the Bonneville and Colorado/Wyoming Chapters of the American Fisheries Society. Grand Junction, CO. March 2003. (won award for best paper by a professional).

A process-driven approach for assessing warmwater streams in Wyoming. Quist, M.C, W.A. Hubert, and F.J. Rahel. Joint meeting of the Bonneville and Colorado/Wyoming Chapters of the American Fisheries Society. Grand Junction, CO. March 2003. (Poster).

The impact of irrigation canals on Bonneville cutthroat trout populations and movement patterns in the Smiths Fork drainage, western Wyoming: A riverscape approach. J.J. Roberts and F.J. Rahel. Colorado-Wyoming Chapter of the American Fisheries Society, Grand Junction, CO, March 2003.

Ontogenetic shifts in habitat use by Bonneville cutthroat trout in the Thomas Fork of the Bear River, Wyoming. S.M. White and F.J. Rahel. Colorado-Wyoming Chapter of the American Fisheries Society, Grand Junction, CO, March 2003.

Using a landscape perspective to understand the dynamics of habitat use by stream fishes. L.A. Thel and F.J. Rahel. Western Division meeting of the American Fisheries Society, San Diego, CA, April 2003. (Poster).

Hierarchical faunal filters: an approach for assessing the effects of habitat and nonnative fishes on native fishes. Quist, M. C., F. J. Rahel, and W. A. Hubert. 64th Annual Midwest Fish and Wildlife Conference, Kansas City, KS, December 2003.

A process-driven approach for assessing warmwater streams in Wyoming. Quist, M. C., W. A. Hubert, and F. J. Rahel. 2003. 64th Annual Midwest Fish and Wildlife Conference, Kansas City, MO, December 2003. POSTER

The importance of habitat patchiness for fishes in a prairie stream. F.J. Rahel. North American Benthological Society meeting. Pittsburgh, PA, June 2002.

GIS applications in stream and river fisheries. W.L. Fisher and F.J. Rahel. 2002. Second International Symposium on GIS/spatial analyses in fishery and aquatic sciences. University of Sussex, Brighton, United Kingdom. September 2002.

Trends in young Bonneville cutthroat trout production and survival: implications for conservation in a landscape impacted by cattle grazing. S.M. White and F.J. Rahel. Society for Conservation Biology meeting. Canterbury, England. July 2002.

Movement patterns in inland cutthroat trout: migrants, residents or a continuum? A.J. Schrank and F.J. Rahel. Ecological Society of America meeting. Tucson, AZ, August, 2002.

The role of ecosystem heterogeneity in reach-scale distribution patterns of young-of-year salmonids. S.M. White and F.J. Rahel. Annual meeting of the Colorado-Wyoming Chapter of the American Fisheries Society. Laramie, WY, February 2002.

Movement patterns in inland cutthroat trout: migrants, residents or a continuum? A.J. Schrank and F.J. Rahel. Annual meeting of the Colorado-Wyoming Chapter of the American Fisheries Society. Laramie, WY, February 2002

Using current biogeographic limits to predict fish distributions following climate change. F.J. Rahel. Invited paper for symposium on Fisheries in a Changing Climate. American Fisheries Society meeting, Phoenix, AZ, August 2001.

How much of nothing is enough? Problems with zero abundance data in fish habitat models. N.P. Nibbelink and F.J. Rahel. Ecological Society of America meeting, Madison, WI. July 2001.

Migration patterns of Bonneville cutthroat trout in the Thomas drainage of Wyoming-Idaho. A.J. Schrank and F.J. Rahel. Annual meeting of the Colorado-Wyoming chapter of the American Fisheries Society. Cheyenne, WY, March, 2001.

Landscape patterns in the abundance of young Bonneville cutthroat trout in the Thomas drainage of Wyoming-Idaho. S. White and F.J. Rahel. Annual meeting of the Colorado-Wyoming chapter of the American Fisheries Society. Cheyenne, WY, March, 2001.

Homogenization of fish faunas across the United States. F.J. Rahel. American Fisheries Society meeting, St. Louis, MO, August 2000.

Movement of Bonneville cutthroat trout in relation to spawning and water quality. A.J. Schrank and F.J. Rahel. Western Division of the American Fisheries Society meeting, Telluride, CO, July 2000.

Temperature tolerances and habitat conditions for Bonneville cutthroat trout in the Thomas Fork of the Bear River, Wyoming. H.C. Johnstone and F.J. Rahel. Western Division of the American Fisheries Society meeting, Telluride, CO, July 2000.

Influences of basin geomorphology and presence/absence of brook and brown trout in southeastern Wyoming: modeling across spatial scales. N.P. Nibbelink and F.J. Rahel. Western Division of the American Fisheries Society meeting, Telluride, CO, July 2000

Climate change and coldwater fishes: what do we know and how do we know it? F.J. Rahel. Invited presentation for National Wildlife Federation-EPA conference "From Kyoto to the Kingdom: The Climate Change-Conservation Connection in New England." Montpelier, VT, Feb. 1999.

Using spatial analysis of errors to improve models of fish-habitat relations. Nibbelink, N.P. and F.J. Rahel. Ecological Society of America meeting, Spokane, WA, August 1999.

Exploring competitive mechanisms that allow non-native brook trout to displace native cutthroat trout in a Rocky Mountain stream. D.C. Novinger and F.J. Rahel. American Fisheries Society meeting, Raleigh, NC, Sept. 1999.

Temperature-mediated competition: do cutthroat trout have thermal refugia from competition with brook trout? D.C. Novinger and F.J. Rahel. Poster at American Fisheries Society meeting, Raleigh, NC, Sept. 1999.

Mechanisms of competition and predation that explain the replacement of cutthroat trout by brook trout in mountain streams. D.C. Novinger and F.J. Rahel. CO-WY Chapter of the American Fisheries Society, Cheyenne, WY, March 1999.

Specificity versus generality in stream fish habitat models: the search for the perfect model. F.J. Rahel. Invited presentation for symposium "Managing across ecological gradients: searching for generalities across variable ecosystems." American Fisheries Society meeting, Hartford, CT, August 1998.

Effects of climate change on habitat for cold water fish species in the Rocky Mountain region. F.J. Rahel. Invited presentation for symposium "Climate change impacts to freshwater fish habitats" American Fisheries Society annual meeting, Hartford, CT, August 1998.

Physiological and behavioral basis for competition between cutthroat trout and brook trout. D.C. Novinger and F.J. Rahel. Annual meeting of the Ecological Society of America, Baltimore, MD, August 1998.

Use of a Geographic Information System (GIS) and large-scale habitat gradients to assess salmonid habitat potential in Rocky Mountain streams. N.P. Nibbelink and F.J. Rahel. CO-WY Chapter of the American Fisheries Society, Grand Junction, CO, March 1998.

The influence of watershed attributes on trout distribution in high-elevation systems. Kruse, C.G., W.A. Hubert, and F.J. Rahel. Annual meeting of the American Fisheries Society, Hartford, CT, August 1998.

Using GIS to understand and predict spatial patterns in fish distributions. F.J. Rahel, J.L. Anderson, N.P. Nibbelink. Invited presentation for symposium on "Spatial aspects of fish ecology." American Fisheries Society meeting, Monterey, CA, August 1997.

Criteria for identifying fish conservation areas: simultaneous consideration of species richness and density. T.M. Patton, W.A. Hubert, and F.J. Rahel. Annual meeting of the American Fisheries Society, Monterey, CA, August 1997.

The Lake Erie fish community: a never-ending story of change. S.A. Ludsin, M.W. Kershner, F.J. Rahel, R.A. Stein, R.L. Knight, K.A. Kayle, and C.T. Knight. Annual meeting of the American Fisheries Society, Monterey, CA, August 1997.

Homogenization of fish faunas across the United States. F.J. Rahel. Annual meeting of the Ecological Society of America, Albuquerque, NM, August 1997.

Managing at the ecosystem level: fisheries management meets conservation biology. F.J. Rahel. Invited presentation. Wyoming Anglers' Symposium, Sponsored by the UW Flycasters Organization, Laramie, WY, April, 1997.

Implications of introduced rainbow trout on native Yellowstone cutthroat trout populations in northwestern Wyoming. C.G. Kruse, W.A. Hubert, and F.J. Rahel. CO-WY Chapter of the American Fisheries Society meeting, Cheyenne, WY, March 1997.

Physiological basis for competitive interactions between Colorado River cutthroat trout and brook trout: swimming energetics. D.C. Novinger and F.J. Rahel. CO-WY Chapter of the American Fisheries Society meeting, Cheyenne, WY, March 1997.

Current distributions and distributional changes in nongame fish species of Wyoming west of the Continental Divide. C.A. Wheeler and F.J. Rahel. CO-WY Chapter of the American Fisheries Society meeting, Cheyenne, WY, March 1997.

Strategies for identifying native species conservation areas: a community approach. T.M. Patton, F.J. Rahel, and W.A. Hubert. CO-WY Chapter of the American Fisheries Society meeting, Cheyenne, WY, March 1997.

Homogenization of fish faunas across the western United States. F.J. Rahel. Invited presentation. Annual Meeting of the Western Division of the American Fisheries Society. Eugene, OR, July 1996.

An introduction to conservation biology. Invited presentation for a continuing education workshop on conservation biology and fisheries management, sponsored by the CO-WY Chapter of the American Fisheries Society, Fort Collins, CO, March 1996.

Status and trends of Wyoming fishes: influence of sampling efficiency and spatial scale when comparing recent and historic surveys, T.M. Patton, F.J. Rahel (presenter), and W.A. Hubert. Annual meeting of the Western Division of the American Fisheries Society. Eugene, OR, July 1996.

Incorporating fisheries databases into a GIS and investigating salmonid biomass, elevation, and gradient relations in Wyoming streams. J.L. Anderson and F.J. Rahel. CO-WY Chapter of the American Fisheries Society meeting, Fort Collins, CO, March 1996.

Changing distributions of warmwater fishes in streams of the Missouri River drainage, Wyoming. T.M. Patton, W.A. Hubert, and F.J. Rahel. CO-WY Chapter of the American Fisheries Society meeting, Fort Collins, CO, March 1996.

Competition among native and introduced salmonids. F.J. Rahel. Invited presentation. Workshop on conservation biology of salmonids in the intermountain west. Sponsored by the U.S. Forest Service. Utah State University, Logan, UT, October, 1995.

Genetic purity, habitat and population characteristics of Yellowstone cutthroat trout in the Greybull River drainage, WY. C.G. Kruse, W.A. Hubert, (presenter), and F.J. Rahel. American Fisheries Society Meeting, Tampa, FL, August 1995.

Applications of GIS to fish distributions and climate change. J.L. Anderson and F.J. Rahel. CO-WY Chapter of the American Fisheries Society meeting, Casper, WY, March 1995.

Evaluating the effectiveness of electrofishing and man-made barriers for controlling brook trout populations in small streams containing cutthroat trout. P.D. Thompson and F.J. Rahel. CO-WY Chapter of the American Fisheries Society meeting, Casper, WY, March 1995.

Use of GIS to explore global warming, habitat fragmentation, and fish distribution patterns. F.J. Rahel, C.J. Keleher, and J.L. Anderson. Invited paper for Symposium on GIS in Fisheries Biology. Annual meeting of American Fisheries Society. Halifax, Nova Scotia. August 1994.

Habitat loss and population fragmentation for coldwater fishes in the Rocky Mountain region in response to global warming. F.J. Rahel, C.J. Keleher, and J.L. Anderson. Invited plenary paper. Symposium on Freshwater Ecosystems and Climate Change in North America: A Regional Approach. Leesburg, Virginia, October, 1994.

Longitudinal patterns of resident salmonids in Rocky Mountain streams: current research at the University of Wyoming. Y. Taniguchi, F.J. Rahel, and J. De Staso III. Annual meeting of the Ichthyological Society of Japan. Tokyo, Japan, March, 1994.

Removal of unwanted brook trout by electrofishing. P. Thompson and F.J. Rahel. Annual Meeting of the Colorado-Wyoming Chapter of the American Fisheries Society, Fort Collins, CO. January, 1994.

Competitive interactions between young Colorado River cutthroat trout and brook trout as influenced by temperature. F. J. Rahel and J. De Staso. Annual meeting of the Colorado-Wyoming Chapter of the American Fisheries Society, Laramie, WY. March 1993.

Effects of diel and seasonal changes in light intensity on invertebrate drift in a subarctic stream in southcentral Alaska. R. Baldwin and F.J. Rahel. North American Benthological Society meeting, Louisville, KY, May 1992.

Potential influences of climatic warming on the distribution of salmonids in the Rocky Mountain region. C. Keleher and F.J. Rahel. Annual meeting of the American Fisheries Society. Rapid City, SD, Sept. 1992.

Influence of temperature on competition between Colorado River cutthroat trout and brook trout. J. De Staso III and F.J. Rahel. Annual meeting of the American Fisheries Society. Rapid City, SD, Sept. 1992.

Foraging in a lethal environment: predation by mudminnows on *Chaoborus* in the hypolimnion of stratified lakes. Annual meeting of American Fisheries Society. Rapid City, SD, Sept. 1992

Elevational distributions of salmonids in Wyoming and potential changes related to climatic warming. C. Keleher and F.J. Rahel. Joint meeting of the CO-WY and Utah Chapters of the American Fisheries Society, Grand Junction CO, Feb. 1992.

Repeated electrofishing as a method for removing brook trout from small streams containing cutthroat trout. C. Keleher and F.J. Rahel. Joint meeting of the CO-WY and Utah Chapters of the American Fisheries Society, Grand Junction CO, Feb. 1992.

Generality of habitat suitability models for young Colorado River cutthroat trout across sites in Wyoming streams. M. Bozek and F.J. Rahel. Annual meeting of the American Fisheries Society, San Antonio, TX, Sept. 1991.

Variability in habitat use by young Colorado River cutthroat trout across sites and among years in Wyoming streams. M. Bozek and F.J. Rahel. Annual meeting of the CO-WY Chapter of the American Fisheries Society, Laramie, WY, March 1991.

Assessing community persistence at different analytical scales. The Fifth International Congress of Ecology. Yokohama, Japan. August 1990.

Tradeoffs in the response of mayflies to low oxygen and fish predation. Ecology Society of America meeting. Snowbird, UT. August 1990.

Behavioral avoidance of conflicting stresses: response of benthic invertebrates to low oxygen and fish predation. C.S. Kolar and F.J. Rahel. Colorado-Wyoming Academy of Science meeting. Laramie, WY. April 1990.